BULLETIN

OF THE

GEOLOGICAL SOCIETY

OF

AMERICA

VOL. 14

JOSEPH STANLEY-BROWN, *Editor*

ROCHESTER
PUBLISHED BY THE SOCIETY
1903

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Judd & Detweiler, Washington, D. C.

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(65 plates; 43 figures.)

PUBLICATIONS OF THE GEOLOGICAL SOCIETY OF AMERICA

Regular Publications

The Society issues a single serial octavo publication entitled Bulletin of the Geological Society of America. This serial is made up of *proceedings* and *memoirs*, the former embracing the records of meetings, with abstracts and short papers, list of Fellows, etcetera, and the latter embracing larger papers accepted for publication. The matter is issued as rapidly as practicable, in covered brochures, which are at once distributed to Fellows and to such exchanges and subscribers as desire the brochure form of distribution. The brochures are arranged for binding in annual volumes, which are elaborately indexed. To this date fourteen volumes have been published and an index to the first ten volumes.

The Bulletin is sold to Fellows of the Society and to the public either in separate brochures or in complete (unbound) volumes. The *prices* are as follows: To libraries and to persons residing outside of North America, five dollars ($5.00) per volume; to persons in North America, not Fellows of the Society, ten dollars ($10.00) per volume (the same amount as the annual dues of the Fellows); to Fellows of the Society, a variable amount, depending on the cost of publication. These prices cover cost of transmission to all parts of the globe. No reduction is made to dealers. Subscribers should specify whether they desire the brochures or the completed volume. Orders should be addrsssed to the Secretary, and drafts and money orders made payable to the *Secretary of the Geological Society of America*, Rochester, New York.

Description of the Published Volumes

Volumes.	Pages.	Plates.	Figures.	Price to Fellows.
Vol. 1, 1889	593 + xii	13	51	$4.50
Vol. 2, 1890	662 + xiv	23	63	4.50
Vol. 3, 1891	541 + xi	17	72	4.00
Vol. 4, 1892	458 + xi	10	55	3.50
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Vol. 6, 1894	528 + x	27	40	4.00
Vol. 7, 1895	558 + x	24	61	4.00
Vol. 8, 1896	446 + x	51	29	4.00
Vol. 9, 1897	460 + x	29	49	4.00
Vol. 10, 1898	534 + xii	54	83	4.00
Index to first ten volumes	209			2.25
Vol. 11, 1899	651 + xii	58	37	4.50
Vol. 12, 1900	538 + xii	45	28	4.00
Vol. 13, 1901	583 + xii	58	47	4.50
Vol. 14, 1902	609 + xii	65	47	4.50

Brochures of Volume 14

Brochures.	Pages.	Plates.	Figures.	Price to Fellows.	Price to the Public.
Proceedings of the Fourteenth Summer Meeting, held at Pittsburg, Pa., July 1, 1902. H. L. Fairchild, *Secretary*	1– 14	1–2	....	$0.25	$0.50
Lower Carboniferous of the Appalachian basin. J. J. Stevenson	15– 96	....	....	.75	1.50

Brochures.	Pages.	Plates.	Figures.	Price to Fellows.	Price to the Public.
Meteorite from Algoma, Wisconsin. W. H. Hobbs	97–116	3–7	1–5	$0.35	$0.70
Pacific mountain system in British Columbia and Alaska. A. C. Spencer	117–132	8–13	....	.40	.80
Was man in America in the Glacial period? N. H. Winchell	133–152	....	1	.20	.40
Marl-loess of the lower Wabash valley. M. L. Fuller and F. G. Clapp	153–176	14–15	1	.35	.70
Shifting of faunas as a problem of stratigraphic geology. H. S. Williams	177–190	16	....	.20	.40
Stratigraphic relations of the Red beds to the Carboniferous and Permian in northern Texas. G. I. Adams	191–200	....	1–3	.15	.30
Ames knob, North Haven, Maine. Bailey Willis	201–206	17–18	....	.15	.30
Submarine valleys off the American coast and in the north Atlantic. J. W. Spencer	207–226	19–20	1–2	.25	.50
Clastic dikes. J. F. Newsom	227–268	21–31	1–19	1.00	2.00
Synthesis of chalcocite and its genesis at Butte, Montana. H. V. Winchell	269–276	....	....	.10	.20
Geographic development of northern Pennsylvania and southern New York. M. R. Campbell	277–296	....	1	.20	.40
Northward flow of ancient Beaver river. R. R. Hice	297–304	32–36	1	.35	.70
Leucite hills of Wyoming. J. F. Kemp and W. C. Knight	305–336	37–46	....	.75	1.50
Paleozoic coral reefs. A. W. Grabau	337–352	47–48	1	.25	.50
Concretions and their geological effects. J. E. Todd	353–368	49–53	....	.40	.80
Studies of the grain of igneous intrusives. A. C. Lane	369–384	54–58	....	.40	.80
Porphyritic appearance of rocks. A. C. Lane	385–406	....	....	.40	.80
Ordovician section near Bellefonte, Pennsylvania. G. L. Collie	407–420	59	....	.20	.40
Genesis of the Amphibole schists and serpentines of Manhattan island, New York. A. A. Julien	421–494	60–63	1–9	1.00	2.00
Proceedings of the Fifteenth Annual Meeting, held at Washington, D. C., December 30 and 31, 1902, and January 1 and 2, 1903, including proceedings of the Fourth Annual Meeting of the Cordilleran Section, held at San Francisco, December 30 and 31, 1902. H. L. Fairchild, *Secretary*	495–609	64–65	....	1.65	3.30

Irregular Publications

In the interest of exact bibliography, the Society takes cognizance of all publications issued wholly or in part under its auspices. Each author of a Memoir receives 30 copies without cost, and is authorized to order any additional number at a slight advance on cost of paper and presswork; and these separate brochures are identical with those of the editions issued and distributed by the Society. Contributors to the proceedings are also authorized to order any number of separate

copies of their papers at a slight advance on cost of paper and presswork; but such separates are bibliographically distinct from the brochures issued by the Society.

The following separates of parts of volume 14 have been issued:

Editions uniform with the Brochures of the Society

Pages	15– 96,*	280 copies.	March	28, 1903.
"	97–116, plates 3– 7;	180 "	April	17, 1903.
"	117–132, plates 8–13;	80 "	"	18, 1903.
"	133–152,	130 "	"	20, 1903.
"	153–176, plates 14–15;	50 "	"	30, 1903.
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"	385–406,	100 "	"	30, 1903.
"	407–420, plate 59;	50 "	October	19, 1903.
"	421–494, plates 60–63;	180 "	December	7, 1903.

Special Editions †

Pages	3– 5,‡	30 copies.	March	20, 1903.
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* 250 copies numbered on bottom of page from 1 to 82.

† Bearing the imprint [From Bull. Geol. Soc. Am., Vol. 14, 1902].

‡ Fractional pages are sometimes included.

Pages 538–542,	130 copies.	March	31, 1904.
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CORRECTIONS AND INSERTIONS

All contributors to volume 14 have been invited to send corrections and insertions to be made in their papers, and the volume has been scanned with some care by the Editor. The following are such corrections and insertions as are deemed worthy of attention:

Page 119, line 21 from top; *insert* before "divided" is
" 131, " 3 " bottom; *for* "latter" *read* former
" 160, " 7 " top; *for* "surfacc" *read* surface
" 160, title of figure 2; *for* "Caemel" *read* Carmel
" 177, plate 16, column B; the space marked 130 represents the Orangeville, Corry and Cussawago formation of I. C. White, Second Pennsylvania Survey, Q. 4.
Page 189, line 4 from top; *for* "formatian" *read* formation
" 193, titles of figures 1 and 2 should be exchanged
" 227, line 7 from bottom; *for* "classic" *read* clastic
" 275, lines 6 and 13 from top; *for* "Emmons" *read* Emmens
" 275; equation 3 should read: $FeS_2 + O_2 + 2\ H_2S$, etcetera
" 275; " 4 should read: $S + O_3 + H_2O$, etcetera
" 276, last line; *for* "solutions from above and" *read* solutions from and above
" 277, line 6 from top; *for* "Read before the Society December 30," 1902, *read* accepted by the Publication Committee May 26, 1903
Page 374, line 17 from top; *for* "on" read of
" 390, " 6 " bottom; *for* "866" *read* 886
" 396, the grain (g) referred to here and elsewhere is measured by the linear dimensions of the grains
Page 402, line 16 from top; *for* "q^q" *read* q^3
" 403, " 10 " top; "x'_{13}," etcetera, refers to the abscissæ of the meeting points of the tangents
Page 408, bottom line; *insert* E. before V. d'Invilliers
" 418, line 6 from top; *for* "cranium" *read* cranidium
" 461, " 4 " top; *for* "$.7854\sqrt{d^2 \text{ or } a}$" *read* d^3
" 465, last column, line 4 from top; *for* "$.7854\sqrt{a \text{ or } d^2}$" *read* d^3
" 465, " " " 13 " top; *for* "d'" *read* d'^2

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 14, PP. 1-14, PLS. 1-2 MARCH 20, 1903

PROCEEDINGS OF THE FOURTEENTH SUMMER MEETING, HELD AT PITTSBURG, PA., JULY 1, 1902

HERMAN LE ROY FAIRCHILD, *Secretary*

CONTENTS

SESSION OF TUESDAY, JULY 1

The Society was called to order at 10.30 o'clock a m, in the chapel of the Oakland Methodist Episcopal Church. In the absence of the President, the First Vice-President, S. F. Emmons, presided throughout the meeting.

ELECTION OF FELLOWS

The Secretary announced that the candidates for fellowship had received a nearly unanimous vote of the ballots sent, and that they were elected, as follows:

Fellows Elected

FRANK M. ANDERSON, B. A., M. S., Berkeley, California. Engaged in field work for State Mining Bureau.

ERNEST ROBERTSON BUCKLEY, B. S., Ph. D., Rolla, Missouri. State Geologist and Director of Bureau of Geology and Mines.

Arthur J. Collier, A. B., A. M., S. B., Washington, D. C. Assistant Geologist, U. S. Geological Survey.

John Burchmore Harrison, M. A., F. I. C., F. G. S., Georgetown, Demerara, British Guiana. Government Geologist.

Edward Henry Kraus, B. S., M. S., Ph. D., Syracuse, New York. Associate Professor of Mineralogy, Syracuse University.

George Davis Louderback, A. B., Ph. D., Reno, Nevada. Professor of Geology, University of Nevada.

George Curtis Martin, B. S., Ph. D., Baltimore, Maryland. Assistant in Paleontology, Johns Hopkins University.

Walter Curran Mendenhall, B. S., Washington, D. C. Geologist, U. S. Geological Survey.

George Henry Perkins, A. B., Ph. D., Burlington, Vermont. Professor of Geology, University of Vermont; State Geologist.

William Sidney Tangier Smith, B. L., Ph. D., Washington, D. C. Assistant Geologist, U. S. Geological Survey.

Alfred William Gunning Wilson, A. B., A. M., Ph. D., Cobourg, Ontario, Canada. Geologist on temporary staff of the Geological Survey of Canada.

DELEGATES TO HUGH MILLER CENTENARY

Upon explanation and motion of the Secretary, it was voted to appoint Dr John M. Clarke as a delegate of the Society to the Hugh Miller centennial celebration at Cromarty, Scotland, October 10, 1902.

On motion of J. A. Holmes, it was also voted to authorize the President and Secretary to appoint other Fellows as delegates to the commemoration if it should appear desirable, Doctor Clarke to be the chairman of the delegation.

Following announcements of excursions, etcetera, the scientific work of the meeting was declared in order. The first paper presented was descriptive of the locality.

GEOLOGY OF THE PITTSBURG REGION

BY I. C. WHITE

The paper was illustrated with maps, charts, and sections. Remarks were made by B. K. Emerson and G. F. Wright. An abstract is printed in *Science*, volume xvi, page 258, August 15, 1902.

As appropriate in this connection, Professor U. S. Grant made an informal report on the geological excursion conducted by Doctor White during the week preceding the meeting. This account has been written as follows:

GEOLOGICAL EXCURSION IN THE PITTSBURG REGION

BY U. S. GRANT

Contents

INTRODUCTION

Previous to the Pittsburg meeting of the Geological Society of America and the American Association for the Advancement of Science, an excursion, lasting from June 23 to June 30, 1902, was arranged for members of these two societies by our Treasurer, Dr I. C. White, of Morgantown, West Virginia.

Pittsburg is the center of one of the most important manufacturing districts in the world, and owes its high commercial standing to the richness of the surrounding district in coal, and latterly in oil and gas. With this city as a center, daily trips were taken in various directions within a radius of 50 miles, and the excursion ended with a trip to Morgantown, 102 miles from Pittsburg. Throughout the excursion there was abundant opportunity to study each day two different sets of phenomena, which may be conveniently grouped under the heads of (1) stratigraphic and economic geology, and (2) physiographic and glacial geology.

STRATIGRAPHIC AND ECONOMIC GEOLOGY

In the region adjacent to Pittsburg are numerous and complete exposures of the rocks from the base of the Lower Carboniferous to the top of the Coal Measures. The formations present are as follows:

Upper Carboniferous or Pennsylvanian	Dunkard formation (Upper Barren Measures).
	Monongahela formation (Upper Productive Measures).
	Conemaugh formation (Lower Barren Measures).
	Alleghany formation (Lower Productive Measures).
	Pottsville formation (Millstone grit).
Lower Carboniferous or Mississippian	Mauch Chunk formation.
	Greenbrier formation (Mountain limestone).
	Pocono formation.

Pittsburg is located on the Conemaugh formation, and the great Pittsburg coal seam (at the base of the Monongahela) caps the hilltops. Within the Conemaugh are several members, one of the most important of which is the Green Crinoidal limestone, which is used as a horizon marker, being recognizable in western Pennsylvania, western Maryland, West Virginia, and Ohio. In the last named state it is known as the Ames limestone.

During the excursion an examination was made of several detailed sections, especially of the Pottsville, Alleghany, Conemaugh, and Monongahela formations, and there was an opportunity to compare sections of these same formations at widely separated localities. In this comparison those who participated in the excursion were impressed with the great extent of some of the thin members of the Coal Measures and with the fact that these thin beds retained their characteristic

features over such a wide territory. Among these members are the Green Crinoidal limestone (Conemaugh) already mentioned, the Freeport coals and the Ferriferous limestone (Alleghany), and the Pittsburg coal (Monongahela).

The strictly economic phase of the trip consisted in visits to (1) a number of coal seams and mines; (2) the McDonald oil field, where an oil well was "shot;" (3) a gas field and a pumping plant in connection with it; (4) the great coking ovens, and especially the by-product coke ovens.

Physiographic and Glacial Geology

At Pittsburg, some 200 feet above the Monongahela and Alleghany rivers, are marked rock benches or terraces, which are covered by deposits of clay, sand, gravel, and boulders. These same terraces can be seen in many localities farther up these two rivers and their main tributaries, the terraces rising upstream. The same benches continue down the Ohio for some distance, and are seen following northward along the Beaver, but they descend in their extension up that stream. The explanation of these features given by I. C. White is that in pre-Glacial times the river, formed by the junction of the Alleghany and the Monongahela, discharged northward along the present Beaver valley into the Lake Erie basin. This northward-flowing stream was dammed back by the ice-sheet and the attendant terminal moraine which was deposited across this valley near Wampum. In the waters thus held to a higher level by the glacial and morainic dams were deposited the clays, sands, and gravels which now cap the rock terraces already mentioned. The rock terraces themselves represent the level to which the streams had eroded their valleys at some time before the advance of the ice from the north; but this time was not necessarily that immediately preceding the ice-sheet, for there is evidence of a period of increased erosion in which the stream had incised narrower channels in the wider level represented by the terraces. R. R. Hice, who has studied these terraces and the glacial phenomena along the Beaver, agrees with White in the interpretation here outlined.

In addition to the phenomena connected with the history of these rivers, the general physiographic aspect of the plateau country west of the mountains was studied and discussed, as were also the terminal moraine and its attendant features.

Personnel of the Excursion

The excursion was under the leadership of Dr I. C. White, State Geologist of West Virginia. Doctor White's intimate acquaintance with the details of the Coal Measure stratigraphy, his unfailing courtesy, and his painstaking efforts to make the excursion profitable and agreeable to each and every one who participated in it, were subjects of constant remark. The excursionists are under obligations to him for the success of the excursion, and to him and Mrs White for their hospitality during the visit to Morgantown. Thanks are also due to J. R. Macfarlane, of Pittsburg; R. R. Hice, of Beaver, Pennsylvania; L. G. Haas, Superintendent of the Baltimore and Ohio railroad, Pittsburg; Mr Young and Mr Cummings, of the Foust Oil Company, Pittsburg; F. G. Ross, engineer of the Apollo Natural Gas Company, Templeton, Pennsylvania, and to O. W. Kennedy, General Manager of the H. C. Frick Coke Company.

The following persons participated in the excursion:

Miss F. Bascom, Associate in Geology, Bryn Mawr College, Bryn Mawr, Pennsylvania.

S. B. Brown, Professor of Geology, West Virginia University, Morgantown, West Virginia.

A. S. Coggeshall, Laboratory Assistant, Carnegie Museum, Pittsburg, Pennsylvania.

L. S. Coggeshall, Laboratory Assistant, Carnegie Museum, Pittsburg, Pennsylvania.

D. E. Crane, engaged in banking, Sewickley, Pennsylvania.

A. R. Crook, Professor of Mineralogy and Economic Geology, Northwestern University, Evanston, Illinois.

C. R. Eastman, in charge of Vertebrate Paleontology, Harvard Museum, Cambridge, Massachusetts.

B. K. Emerson, Professor of Geology, Amherst College, Amherst, Massachusetts.

H. L. Fairchild, Professor of Geology, University of Rochester, Rochester, New York.

A. W. Grabau, Adjunct Professor of Paleontology, Columbia University, New York city.

U. S. Grant, Professor of Geology, Northwestern University, Evanston, Illinois.

C. M. Hamilton, reporter, Pittsburg *Dispatch*, Pittsburg, Pennsylvania.

J. B. Hatcher, in charge of Paleontology, Carnegie Museum, Pittsburg, Pennsylvania.

R. R. Hice, manufacturer, Beaver, Pennsylvania.

J. R. Macfarlane, lawyer, Pittsburg, Pennsylvania.

G. C. Martin, Assistant in Paleontology, Johns Hopkins University, Baltimore, Maryland.

Miss L. K. Miller, Dean of Lowthorpe, Groton, Massachusetts.

Miss Ida H. Ogilvie, student, Columbia University, New York city.

F. H. Oliphant, Geologist for Standard Oil Company, Oil City, Pennsylvania.

A. E. Ortmann, Curator of Invertebrate Paleontology, Princeton University, Princeton, New Jersey.

F. B. Peck, Professor of Geology and Mineralogy, Lafayette College, Easton, Pennsylvania.

Sidney Prentice, Paleontological Draughtsman, Carnegie Museum, Pittsburg, Pennsylvania.

C. S. Prosser, Professor of Geology, Ohio State University, Columbus, Ohio.

H. W. Shimer, Assistant in Paleontology, Columbia University, New York city.

A. E. Turner, President of Waynesburg College, Waynesburg, Pennsylvania.

I. C. White, State Geologist, Morgantown, West Virginia.

J. C. Williams, engaged in coal and clay work, Ridgeway, Pennsylvania.

The next paper, in the absence of the author, was read by title.

LOWER CARBONIFEROUS OF THE APPALACHAIN BASIN

BY J. J. STEVENSON

The paper is printed in full in this volume.

The following paper was read by its author:

METEORITE FROM ALGOMA, WISCONSIN

BY W. H. HOBBS

The paper was discussed by W. M. Davis, O. C. Farrington, B. K. Emerson, the author, and Henry A. Ward and other visitors. It is printed in full in this volume.

Mr James R. Macfarlane, chairman of the Local Excursion Committee, made announcements concerning the excursion during the week. Dr F. P. Gulliver, Secretary of Section E, American Association for the Advancement of Science, made announcements relating to events of the week.

The next paper was entitled

METEORITES OF NORTHWESTERN KANSAS

BY O. C. FARRINGTON

[*Abstract*]

Of the thirteen meteorites known from Kansas, six have been found within an area 115 miles long by 85 miles broad, in the northwestern part of the state. As these all resemble each other in outward appearance, the question has been raised as to whether they belong to a single fall. In deciding the question the probable course of a meteor and the structure and composition of the meteorites should be discussed. It is shown that the probable course of the meteor would have been from southeast to northwest and not from southwest to northeast, as would be required if the meteorites belonged to a single fall. As regards structure and composition, three of the meteorites have been studied while the other three have not. Results of studies of two of the latter, Long Island and Franklinville, are given and the Long Island meteorite shown to be, in several respects, remarkable. The conclusion is reached that two of the meteorites may belong to one fall, but that the others are single individual falls.

The last paper of the morning session was

MOHOKEA CALDERA ON HAWAII

BY C. H. HITCHCOCK

The general geographical features of the island of Hawaii are shown in a small map in my paper, "Volcanic Phenomena on Hawaii." * Three dome-shaped elevations are there represented: Mauna Kea, 13,810 feet; Mauna Loa, 13,650 feet, and Hualalei, 8,275 feet in altitude. Of these, the second is the most symmetrical, and sustains the two calderas of Mokuaweoweo and Kilauea. On its eastern and

* Bull. Geol. Soc. Am., vol. 12, p. 52.

western sides the slope is gradual and continuous to the sealevel. On the southeast side the lower part of the slope seems to have been interrupted by fractures and the subsidence of large segments of the crust.

These and other characteristics are shown finely upon the recent (1901) map of Hawaii on the scale of 1 inch equals 10,000 feet, and executed under the direction of W. D. Alexander.*

The southerly sides of the Mauna Loa dome have been fractured somewhat differently from those on the northeast, as evidenced by the eruptions of 1868 and 1887, as compared with those of 1843, 1855, 1880–'81, and 1899. The discharge of lava was rapid through long rents, preceded by vigorous earthquakes in the former. In the latter the discharge has been effected through comparatively small orifices—sometimes gushing forth in fountains, sometimes flowing slowly for months down the mountain's side.

As is well known, the term "caldera" was applied by Captain C. E. Dutton to the three great pit-craters of the territory of Hawaii—Mokuaweoweo, Kilauea, and Haleakala. Each one is an immense depression, "formed by the dropping of a block of the mountain crust which once covered a reservoir of lava." Within the pit there may be true craters, consisting of lapilli that have been subsequently ejected from beneath.

Now in Kau, on the southeast side of Mauna Loa, there have been great disturbances, giving rise to precipices and blocks of basalt of mountainous dimensions, some of which may have been depressed and others elevated, the whole group resembling the buttes of the region of the Cordilleras, with which they were compared by Captain Dutton. In 1895 J. S. Emerson, of Honolulu, read a paper, "Some characteristics of Kau," before the Social Science Association, which will be published in the American Journal of Science. In this he argues the former presence of vigorous volcanic action among these hills back of Hilea; and, among other things, he suggests the possible derivation of the abundant volcanic ashes from some ancient vent in the Hilea-Mohokea region, rather than from Mokuaweoweo or Keokeo. It was from Mr Emerson that I first learned of the existence of these singular mountains, but it was not until the new map of Hawaii was inspected that the configuration suggested the presence of an immense caldera at the base of Mauna Loa. Perceiving that the largest area of the depression had the name of Mohokea, I proposed to apply that name to the caldera. This paper was entered for the Rochester meeting, but was then read only by title.

The Mohokea caldera is a depression carved out of the southern slope of Mauna Loa, embracing an area of exceeding 30 square miles, largely occupied for the cultivation of the sugar cane. The longest diameter is 7 miles and the width is 5 miles. It differs from Kilauea in that one side has been broken down, and it contains several islands or blocks, mostly depressed below the adjoining slope. Kaiholena is higher than the slope behind it. The inclination from the highest back wall to the front base amounts to 4,500 feet. The base in front may be placed at 1,200 feet; that behind at 4,000 feet; and three-fourths of the border has a wall 500 feet high. The mountainous blocks are mostly in two parallel lines, though it is likely that a careful survey would exhibit irregularities. The name of the outermost block of the eastern line is Puu Enuhe. Behind it runs into Kulua or Pukulua, the whole range being 4 miles long. Makanao lies in the opening of the

* A photographic copy was shown at the time of the presentation of this paper.

caldera, opposite Puu Enuhe. Behind it is Kaiholena, 3,824 feet, the highest of these buttes. Puu Enuhe has the altitude of 2,327 feet.

All these elevations and the whole interior are covered by an abundant thickness of volcanic ashes—apparently the same deposit with those I have described in the paper cited above—and believed to have been ejected from Mokuaweoweo in prehistoric times.

There are streams of aa between Hilea and Honuapo which seem to have come from the lower part of Mohokea, but at a date subsequent to the formation of the caldera and the deposition of the ashes. The more western flow is a mile and a half in width. The more eastern flow starts from between two hills, just like the other, but a mile away. The foreground of Dutton's view of the Hilea butte is a field of aa.

As this is the largest and most peculiar of all the Hawaiian calderas, it will arrest the attention of travelers. Professor Alexander's map also shows another smaller caldera, similarly situated, near Kapapala.

Following Professor Hitchcock's paper, Dr I. C. White gave notice relating to his proposed excursion up the Beaver river Wednesday afternoon.

The Society adjourned for the noon recess, and reconvened at 2.20 o'clock p m. The first paper of the afternoon session was

ELLIPSOIDAL STRUCTURE IN PRE-CAMBRIAN ROCKS OF LAKE SUPERIOR REGION

BY J. MORGAN CLEMENTS

[*Abstract*]

The greenstones of pre-Cambrian age in the Lake Superior region have very commonly developed in them a structure which, since the masses separated by this structure are ellipsoidal, is designated "ellipsoidal" structure. *

A review of the ideas held by various observers concerning the origin of this structure is given, and it is concluded that it is an original structure, due to breaking up of a viscous lava while it was being extruded. The structure is shown to be of very widespread occurrence, especially so in the greenstones of the Lake Superior region.

The desirability of using the term "ellipsoidal," instead of "spheroidal," in referring to this structure is urged in view of the fact that it is an original structure, and that the bodies formed by this structure are ellipsoidal, whereas the spheroidal structure in the rocks is of secondary nature, and is due to exfoliation caused by weathering.

In discussion of the paper remarks were made by J. A. Holmes, U. S. Grant, W. M. Davis, C. H. Hitchcock, and the author.

* This structure was described and illustrated by means of the lantern slides.

The second paper was by the same author.

VERMILION DISTRICT OF MINNESOTA

BY J. MORGAN CLEMENTS

[*Abstract*]

The Vermilion district occurs in northeastern Minnesota, extending from Vermilion lake north 70 degrees east to Gunflint lake, on the international boundary. As described, the district is about 80 miles long by 4 to 10 miles in width. The area surveyed comprises nearly 1,000 square miles. The stratigraphic succession is as follows, given in descending order:

Pleistocene	Glacial drift.
Keweenawan	Great gabbro and Logan sills.
(Unconformity.)	
Upper Huronian (Animikie series), confined to east end of district	Upper slate formation. Gunflint formation (iron-bearing formation).
(Unconformity.)	
Lower Huronian	Intrusives. Knife slates. Lower Huronian iron-bearing formation. Ogishke conglomerate.
(Unconformity.)	
Archean (Vermilion series)	Intrusive granites, porphyries, and greenstones. Soudan formation (the iron-bearing formation). Ely greenstone, an ellipsoidally parted basic igneous and largely volcanic rock.

The structure is complex. The Vermilion district is broadly a great complex synclinorium bounded on the north by the Archean granite and on the south by Huronian granite, Keweenawan gabbro, with the Upper Huronian slates coming in for a short distance. The ores are high grade hematites occurring in structural basins. First, the iron comes from preëxisting rocks, and it is deposited to form the sedimentary iron-bearing formations. In the case of the Archean Soudan iron-bearing formation the iron comes from the Archean greenstone (basic and intermediate intrusives and volcanics). Second, after the folding the iron is leached from the iron-bearing formation chiefly, and after being carried down by descending meteoric waters is precipitated as the oxide in places favorable for its accumulation, thus forming the ore deposits.

The paper was illustrated by lantern slides. Remarks were made by C. R. Van Hise and U. S. Grant.

The following paper was presented:

PACIFIC MOUNTAIN SYSTEM IN BRITISH COLUMBIA AND ALASKA

BY ARTHUR C. SPENCER

Remarks were made by B. K. Emerson. The paper is printed in this volume.

The last paper was presented in abstract by W. M. Davis.

DEVELOPMENT OF THE SOUTHEASTERN MISSOURI LOWLANDS

BY C. F. MARBUT

[*Abstract*]

The lowland region of southeastern Missouri consists of two broad belts of flat lowland with a discontinuous ridge between them. One of the lowland belts is an abandoned valley of the Mississippi river, the other is the valley of the Ohio. The Mississippi river has gained its existing valley by two successive changes, abandoning first about 200 miles of its original valley, and later about 20 more. It was led to abandon its valley because of a shorter and steeper course having been offered it by the Ohio. The Ohio drainage first captured some small tributaries of the Mississippi, and later the Mississippi turned itself into these valleys in succession by sapping the ridge between. Since the capture of the Mississippi several of the smaller rivers of the region have abandoned their older valleys.

The paper is printed in "University of Missouri Studies."

The Secretary spoke of the successful efforts of Dr J. M. Clarke for a memorial tablet on the Emmons house in Albany, New York, and submitted the following matter for record:

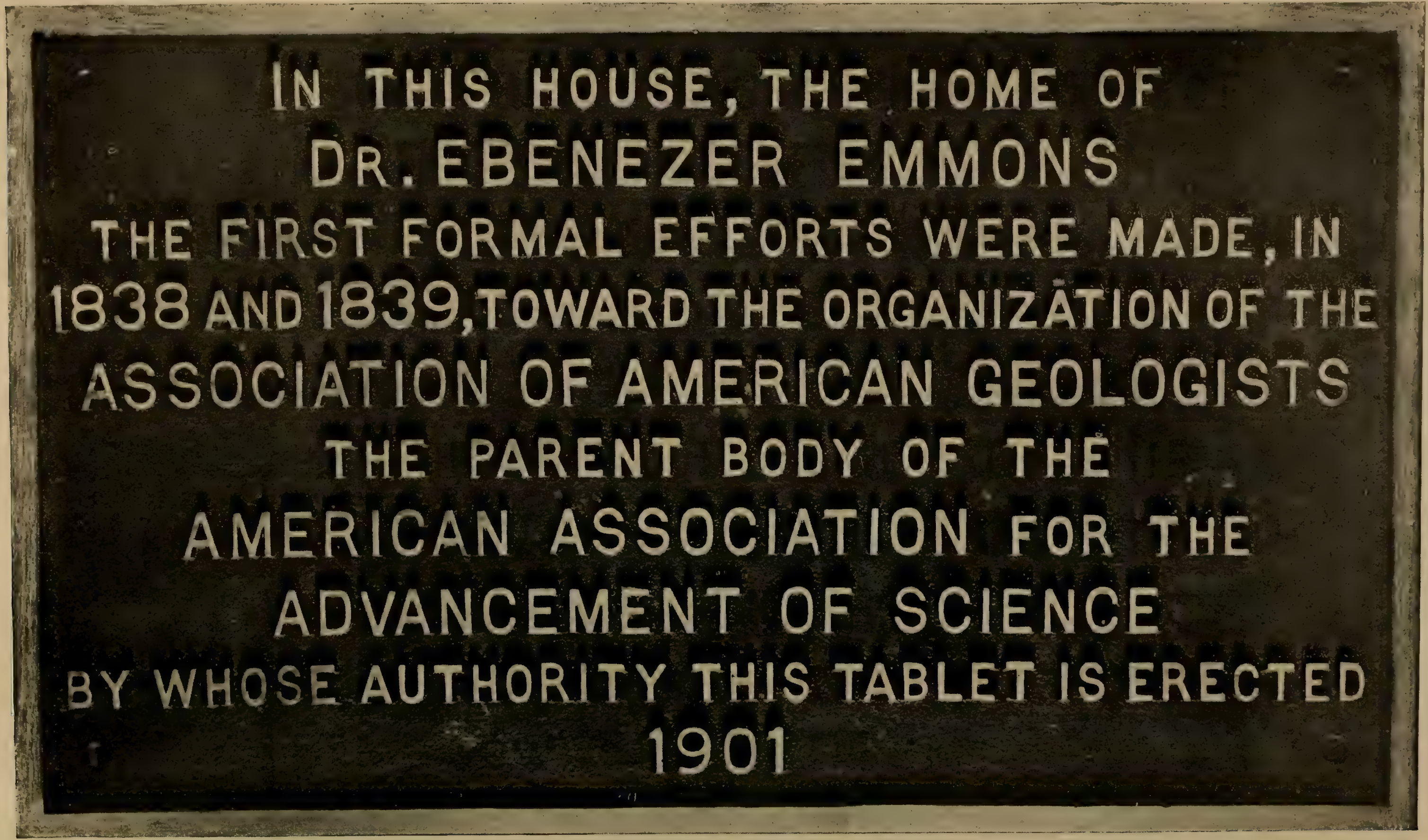
MEMORIAL TABLET ON THE EMMONS HOUSE, ALBANY, NEW YORK

With the approbation of the Geological Society of America, and with Section E, American Association for the Advancement of Science, as intermediary, a memorial was brought before that Association at its New York meeting, 1899, by Dr John M. Clarke, urging the Association to approve the erection of a tablet (see plate 1) on the house in Albany which was formerly the home of Dr Ebenezer Emmons, State Geologist of New York in charge of the Second Geological District, 1836–1842, to commemorate the fact that the Association looks on this house (see plate 2) as the place of its birth.

At its Denver meeting, August, 1901, the Association received and adopted the report from its committee recommending the proposition, and as this report is an interesting record of an important event in the history of American geology, it is given herewith:

Report of Committee of American Association for the Advancement of Science on the Emmons House Memorial

The American Association for the Advancement of Science was organized in 1847. It was the organic descendant and enlarged outgrowth from the Association of American Geologists and Naturalists. The latter body was created in 1842 by the incorporation of the Naturalists within the Association of American Geologists.



EMMONS MEMORIAL TABLET

Erected January 10, 1902—159 Hudson avenue, Albany, New York

EMMONS HOUSE, ALBANY, NEW YORK

Showing position of Memorial Tablet. The house is on the corner of Hudson avenue and High street

The Association of American Geologists is therefore to be looked on as the legitimate organic ancestor of the American Association for the Advancement of Science.

The circumstances which led up to the organization of the Association of American Geologists are as follows:

During the prosecution of the geological survey of the state of New York the need of the geologists for consultation and interchange of views with others engaged in official geologic work led to the suggestion of an organization of a body of American geologists.

It appears that Lieutenant W. W. Mather, one of the New York geologists, suggested the subject of such a meeting to the Board of Geologists in November, 1838. He wrote:

"Would it not be well to suggest the propriety of a meeting of the geologists and other scientific men of our country at some central point next fall, say in New York or Philadelphia? There are many questions in our geology that will receive new light from friendly discussion and the combined observation of various individuals who have noted them in different parts of our country. Such a meeting has been suggested by Professor Hitchcock, and to me it seems desirable. It would undoubtedly be an advantage not only to science but to the several surveys that are now in progress and that may in future be organized. It would tend to make known our scientific men to each other personally, give them more confidence in each other, and cause them to concentrate their observations on those questions that are of interest either in a scientific or economical point of view. More questions may be satisfactorily settled in a day by oral discussion in such a body than in a year by writing and publication." *

It appears herein that the suggestion of this meeting was originally made by President Edward Hitchcock, of Massachusetts, who was the first to receive the appointment as geologist of the first district of New York from Governor Marcy. President Hitchcock has said in regard to the suggestion made by Lieutenant Mather:

"As to the credit he has here given me of having previously suggested the subject, I can only say that I had been in the habit for several years of making this meeting of scientific men a sort of hobby in my correspondence with such." †

Lieutenant Mather's letter to the Board of Geologists was taken up for consideration at a meeting held November 20, 1838, at the house of Dr Ebenezer Emmons corner of High street and Hudson avenue, Albany.‡

The action taken by the geologists was one of unanimous approval of the proposition, and Lardner Vanuxem, of the third district, was commissioned to open communication with other geologists, specially with President Hitchcock, with reference to carrying this project into effect. The undertaking was not immediately successful, and at a meeting held in the autumn of 1839 the purpose of the geological board was reiterated. This meeting was also held at Doctor Emmons' house, the four geologists and the paleontologist being present, and also Ebenezer Emmons, Jr., who still survives. As a result of the second undertaking on the part of the New York geologists, a meeting was called in Philadelphia for April, 1840, where and when the organization of the Association of American Geologists was effected. The following year the Association again met in Philadelphia, when

* Letter from W. W. Mather to the Geological Board of New York, dated November 9, 1838, and addressed to Professor Emmons.

† Address of President Edward Hitchcock at the inauguration of Geological Hall at Albany, August 27, 1856. New York State Cabinet of Natural History, Tenth Annual Report, 1857, p. 23.

‡ See documents hereto appended, being A, a statement dictated by Professor James Hall, August 24, 1896, and B, a statement dictated by Ebenezer Emmons, Jr., February, 1900.

the membership of the body was largely increased, and in 1842 the place of meeting was Boston, and then, as already rehearsed, both the name and scope of the Association were, at the solicitation of the naturalists, enlarged. President Hitchcock, addressing the New York public interested in the outcome of the work of their geologists, makes the following statement in the address already quoted:

"It may be thought that the New York geologists in their invitation and the members of that first Philadelphia meeting had no thought of extending their Association beyond geologists, but Professor Mather's language just quoted speaks of 'a meeting of the geologists and other scientific men of our country,' thus showing what were his aspirations, and they were shared by all of us who had anything to do with that first meeting. But we knew that only a short time previous the American Academy of Arts and Sciences, at Boston, had directed a request to the American Philosophical Society, as the oldest of the kind in the country, that it would invite the scientific men of the land to such a meeting as the one we are now enjoying, but the distinguished men of that society declined through fear that the effort would prove a failure. Surely, then, it did not become us to announce any such intentions or expectations; yet we did talk of them, and could not but hope that what might fail if attempted on a large scale at first might be accomplished step by step. Had not the New York geologists issued that modest invitation and confined it at first to the state surveyors, probably even yet we might have been without an association for the advancement of science." *

The committee appointed by this Association to consider the matter of placing a memorial tablet on the Emmons house in Albany, New York, begs to submit the foregoing as evidence of the prenatal history of the American Association and to recommend that this house, the home of the late Ebenezer Emmons, a man of eminence in his profession, of untiring diligence and enduring patience, be permanently marked by a tablet setting forth the interest of that spot to the history of the Association. It is suggested that such tablet bear the following inscription:

IN THIS HOUSE, THE HOME OF

DR EBENEZER EMMONS,

THE FIRST FORMAL EFFORTS WERE MADE, IN
1838 AND 1839, TOWARD THE ORGANIZATION OF THE

ASSOCIATION OF AMERICAN GEOLOGISTS,

THE PARENT BODY OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT
OF SCIENCE, BY WHOSE AUTHORITY THIS TABLET IS ERECTED.

1901.

The committee further reports that the cost of this tablet will constitute no claim on the treasury of the association, but will be borne individually by one of its members, Dr T. Guilford Smith.

(Signed)

JOHN M. CLARKE, *Chairman.*
C. H. HITCHCOCK.
J. McK. CATTELL.
W J McGEE.

A. Statement dictated to John M. Clarke by Professor James Hall, August 24, 1896:

The organization of a body of American geologists was proposed by the four geologists at Doctor Emmons's house at the corner of Hudson avenue and High street

* Address of President Edward Hitchcock, as cited.

It was during the fall of 1838. Vanuxem was asked to see or communicate with the Rogerses concerning it, but nothing came of it that year. The next year we reiterated our purpose, as the intention was to get some means of comparing our results with those of other geologists in other states, especially in Pennsylvania. This meeting was held at Doctor Emmons's house, the four geologists being present and perhaps also Conrad. Ebenezer Emmons, Jr., was also there. We then decided to communicate again with the Rogerses and others for the end already suggested and to organize a society of geologists for this especial purpose. We wanted to compare our results with those of others and make up our nomenclature, and we had to do it soon, as we were required to publish. As a result of this unanimously expressed purpose, a meeting was called for April, 1840, in Philadelphia. I was present then, but not at the second Philadelphia meeting in 1841, as that year I was off in May and June with D. D. Owen on a flatboat sailing down the Ohio, sleeping on a box and collecting fossils all along from Louisville to New Harmony. As far as Rogers was concerned, the meeting came to naught. He was not ready with his results and gave them only at the third meeting at Boston in 1842. It was here that the naturalists proposed to join us, and we agreed thereto, but the Boston meeting was called as the meeting of the Association of American Geologists, and in the course of that meeting the name was changed to that of Association of American Geologists and Naturalists.

B. Statement dictated to John M. Clarke by Ebenezer Emmons, Jr., February, 1900:

I was present at the meeting of the four geologists at my father's house, in 1838. I was then about 16 years old, and had assisted my father in his field work and making drawings and sketches. Mr Conrad, the paleontologist, was also present. I recollect that the board of geologists then authorized Mr Vanuxem to open correspondence with others for the purpose of effecting an organization.

In pursuance of this action a bronze tablet, measuring 14 by 24 inches, has been placed on the old Emmons house at the corner of Hudson avenue and High street, Albany, and serves to commemorate in some measure the services to American science of the four state geologists of the Geological Survey of New York (1836–'42).

The following resolution of thanks was offered by J. A. Holmes and unanimously adopted by rising vote:

Resolved, That the thanks of the Geological Society of America are heartily extended to the Pittsburg Local Committee and the trustees of the Oakland Methodist church for the generous provision for the meeting of the Society; to Mr James R. Macfarlane, Chairman of the Local Excursion Committee, for his labors in connection with the geological excursions, and to Dr I. C. White for his extended excursion through the Pittsburg and Monongahela regions.

The Society then adjourned.

Register of the Pittsburg Meeting, 1902

The following Fellows were in attendance at the sessions of the Society:

Florence Bascom.
J. M. Clements.
W. M. Davis.
C. R. Eastman.
B. K. Emerson.
S. F. Emmons.
H. L. Fairchild.
O. C. Farrington.
A. W. Grabau.
U. S. Grant.
F. P. Gulliver.
J. B. Hatcher.
C. H. Hitchcock.
W. H. Hobbs.
J. A. Holmes.
E. E. Howell,
J. R. Macfarlane.
F. B. Peck.
Charles Schuchert.
A. C. Spencer.
J. W. Spencer.
C. R. Van Hise.
I. C. White.
R. P. Whitfield.
S. W. Williston.
A. A. Wright.
G. F. Wright.

Present at the meeting of the Society, 27.

Fellow-elect

George C. Martin.

The following Fellows were in attendance at the meeting of Section E, American Association for the Advancement of Science:

M. R. Campbell.
J. M. Clarke.
R. T. Hill.
W J McGee.

Total attendance, 31.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 14, PP. 15-96 MARCH 28, 1903

LOWER CARBONIFEROUS OF THE APPALACHIAN BASIN

BY JOHN J. STEVENSON

(Presented before the Society July 1, 1902)

CONTENTS

Introduction

It is the writer's purpose in this work to describe in detail the Carboniferous deposits of the Appalachian basin, to correlate them, to ascertain as far as possible the conditions existing during the deposition of the various rock masses, and finally to apply the facts in a discussion of the origin of coal and coal beds.

Appalachian basin, as here used, refers to the area bounded at the east by the old Appalachian land, at the west by the Cincinnati uplift to central Kentucky, and thence southward to Alabama by the area whence erosion has removed the newer rocks and thereby separated the eastern from the western Carboniferous region. In a general way, it includes Pennsylvania, Maryland, and Virginia west from the Blue ridge, the whole of West Virginia, eastern Ohio and Kentucky, east-central Tennessee and northern Alabama. In Alabama the Appalachian and Mississippi areas are continuous; in Tennessee they are separated by the Great Central valley, while in Kentucky the dividing strip is but a few miles wide. The basin, as thus rudely defined and with an extent of probably 150,000 square miles, was almost wholly covered with Carboniferous rocks of one period or another; but the beds have been removed from nearly one-half of it, so that in some portions, especially at the east, there remain only outlying strips, preserved in synclinals or along the borders of great overthrust faults.

A general description of the deposits is possible now because of the detailed work done by the geologists of Pennsylvania, Ohio, Maryland, and West Virginia at the north, as well as by those of Tennessee and Alabama at the south, supplemented by the studies of the United States geologists and others in Kentucky, Virginia, and Tennessee. The detailed work of the United States geologists for the most part is still unpublished, and one has within reach only the synopses given in connection with the individual folios. Acknowledgment of the writer's indebtedness to these observers is made in the proper connection. It is more than probable that there are omissions or errors in the references, and that there are misinterpretations in statements of other's opinions. As such defects not only do injustice to fellow-students in the same field, but also detract from the usefulness of the work, the writer urges those who detect them to inform him, that the corrections may be published with the succeeding chapter.

In the descriptive portions the names applied to formations will be, as far as possible, those employed by the geologists whose work is quoted for a locality, but questions of nomenclature will be considered in the discussion closing each chapter. The names employed by the second

Geological Survey of Pennsylvania for formations along the eastern outcrop are:

Lower Carboniferous (Mississippian)...	Mauch Chunk. Pocono.
Upper Devonian......................	Catskill. Chemung. Hamilton.

The Pocono of Lesley; Vespertine of Rogers

DISTRIBUTION AND CHARACTERISTICS OF THE ROCKS

Nomenclature.—To the lower division of the Mississippian in Pennsylvania, Professor H. D. Rogers applied the name Vespertine, which was not accepted generally by geologists. Many years later Professor J. P. Lesley offered instead the geographical name, as the formation had been described by him as characteristically developed in the Pocono mountains of eastern Pennsylvania. This term was used in the Pennsylvania reports, and it has been adopted by the Maryland survey as well as by some of the United States geologists.

In the eastern part of the Appalachian basin, the Pocono, containing many thick beds of hard rocks, is a notable mountain maker. It surrounds the anthracite coal fields of Pennsylvania, the Broad Top coal field of the same state, and a small outlier remains farther east in Fulton county, almost on the edge of the Great valley; the outcrop is practically continuous along the Alleghenies of Pennsylvania, and similarly long outcrops are shown along the Alleghenies and other mountains in Maryland and the Virginias. The character changes westwardly along the northern border, but the information now available renders recognition of the varying conditions a matter of little difficulty.

For knowledge of this formation along the northern and eastern exposures in Pennsylvania geologists are indebted to Messrs J. F. Carll, H. M. Chance, and C. A. Ashburner, but especially to Dr I. C. White, whose reports cover by far the larger part of the area within which the Pocono is shown. For this reason the writer prefers Doctor White's measurements and determinations to his own, where the observations overlap in that state, the more so because those by Doctor White are later in date and are to be regarded as completing his study of the formation in Pennsylvania.

The region to be studied in review is so large that it must be described in areas, the first being that in Pennsylvania and Maryland eastward from the Allegheny plateau, which may be termed

The anthracite strip.—The most northerly exposures, respecting which detailed information exists, are in the northern Anthracite field, within Wayne county, at about 10 miles south from the New York line. There the section* is

	Feet
1. Sandstone	40
2. Shale and sandstone	200
3. Massive sandstone	125
4. Shale and current bedded sandstone	265
5. Griswold Gap conglomerate	35
6. Sandstone and shale, imperfectly exposed	150
7. Sandstone and sandy shale	200
8. Mount Pleasant conglomerate	25
Total	1,140

Doctor White is inclined to regard the beds below number 5 as transition from the Catskill. He finds great resemblance between the highest sandstone of the section and the Shenango sandstone of Crawford county, which in the northwestern part of Pennsylvania is the most notable feature of the Pocono. The Mount Pleasant conglomerate is recognizable in Monroe county, 20 miles farther east.† Near Pittston the thickness is less, only 753 feet, of which the upper 353 feet‡ is mostly massive sandstone, but the increase southward and southwestward in the other fields is very notable, for the upper portion becomes 600 feet at Shickshinny and between 700 and 800 feet in the gaps of Little mountain. Thin irregular streaks of coal occur in this portion on North mountain which separates Columbia and Luzerne counties.§ Mr Winslow's sections, as given by Professor Lesley, though measured instrumentally, do not differ materially from those of Doctor White. Including the transition beds, he finds 1,177 feet in the northern field, 1,110 feet on Nescopec mountain, and 1,253 feet near Mauch Chunk, all sandstone except about 75 feet at the last locality.||

According to H. D. Rogers's summary description, the Pocono (Vespertine) shows greatest thickness and coarseness at the southeast. It is 2,000 feet on the Susquehanna, 1,800 feet at Pottsville, 1,100 feet in the Nescopec mountain, while in the mountains enclosing the Northern or Wyoming field it is but 500 or 600 feet. The section at Pottsville is

*I. C. White: Geology of Wayne and Susquehanna counties (G 5), 1881, p. 56.

†I. C. White: G 5, p. 90.

‡I. C. White: Geology of the Susquehanna region (G 7), 1883, p. 39.

§I. C. White: G 7, pp. 47–49.

|| J. P. Lesley: A summary description of the geology of Pennsylvania, vol. ii, 1892, p. 1635. This will be quoted as Final Report.

	Feet
1. Sandstone, more or less conglomerate	521
2. Slate	22
3. Sandstone with much conglomerate	726
4. Sandstone with little conglomerate	240
5. Sandstones variegated	409
Total	1,918

Underlying this he found 687 feet of red, gray, olive, and yellow sandstones, with some shale and some conglomerate, which he regarded as transition. These lower beds are 525 feet on the Susquehanna and less than 400 feet in Nescopec and Shickshinny mountains.* Professor Claypole made the total thickness at the Susquehanna in Perry county about 1,950 feet.†

The measurements made by Doctor White and by the writer along the westerly side of the Broad Top coal field, in Huntingdon and Bedford counties of Pennsylvania, show the thickness to be not far from 1,100 to 1,200 feet, and the section consists mostly of sandstone; but at somewhat more than 400 feet above the bottom Doctor White discovered a thick bed of shale, portions of which are rich in *Spirifer*, *Rhynchonella*, and productoid forms. Not a few of the sandstones show some conglomerate. Mr Ashburner reports a thickness of 2,133 feet in Sideling hill, on the east side of this field in Huntingdon county, which appears to be excessive, being greater than that obtained by Claypole on a line of outcrop which should pass nearly 20 miles eastward from Sideling hill, and being nearly double the thickness observed by Stevenson in eastern Fulton county, where it appears not to exceed 1,100 feet. Evidently, as suggested by Doctor White, beds belonging to a lower series have been included.

In eastern Bedford of Pennsylvania and in Allegany of Maryland the thickness varies little from 1,100 to 1,000 feet. The mass consists almost wholly of sandstones, some of them conglomerate and becoming coarser in Maryland, where the pebbles are sometimes three-fourths of an inch long.‡ Streaks of coal, usually not more than 3 or 4 inches thick, are found at various horizons, but especially in the upper portion. Whether or not any of these are continuous to any considerable distance could not be ascertained. Owing to the flattening of the anticlinals southward, exposures within this area cease at a little way beyond the Virginia line.

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* H. D. Rogers: Geology of Pennsylvania, 1858, vol. ii, pp. 8, 9.

† E. W. Claypole: Prelim. Rep. on Palæontology of Perry county (F 2), 1885, p. 227.

‡ C. C. O'Harra: Maryland Geological Survey, Allegany county, 1900, p. 109.

The Allegheny plateau.—Returning now to the north and following the backbone of the Allegheny plateau, a line of outcrop about 30 miles westward from that nearest in the anthracite fields, one finds a notable decrease, for in western Wyoming county Doctor White gives but 300 feet for entire thickness of the Mississippian,* and in Sullivan it appears to be no greater. In Lycoming county, which lies on both sides of the Allegheny crest, numerous measurements by Franklin Platt and Andrew Sherwood are available. In the northeast corner Mr Sherwood estimates the Mississippian at 813 feet, of which he places 480 feet in the Pocono. Mr Platt, however, averages the interval for the same area at 730 feet, of which he thinks 665 feet should be referred to the Pocono. Mr Platt's section is the more satisfactory, as the exposure is practically complete. The rock is almost wholly current-bedded sandstone, and shows a one-foot coal bed at 80 feet from the bottom. In northwestern Lycoming Mr Platt finds, beginning at 120 feet below the Pottsville, gray current-bedded sandstones 350 feet thick and resting on red shales and sandstones of the Catskill.† No conglomerate is reported in any of the Lycoming sections. The measurements in Bradford county are rather indefinite, but Mr Platt found in the Barclay coal field a greenish gray current-bedded sandstone 300 feet thick, beginning at 110 feet below the Pottsville. Professor Lesley, quoted by Mr Platt, describes these rocks as "gray flaggy sandstone" several hundred feet thick.‡ No conglomerate appears in this county. It is evident that the lower transition beds have practically disappeared.

Doctor Chance's upper Pocono, in Clinton county, varies little from 400 feet, and consists of 60 to 80 per cent sandstone, the rest being sandy shale. At 15 feet from the top is a layer 3 feet thick, composed of mixed limestone and sandstone, but in no sense a conglomerate. The sandstone overlying it is rather coarse and gray. The sandstones, which for the most part are hard, massive, fine grained, and show a foliated or laminated structure, are made up of rounded grains and are usually greenish gray. The lower layers are coarse, and some contain pebbles.§ Doctor Chance's lower Pocono represents the remnant of the disappearing Catskill with the upper shales of the Chemung. For the most part it appears to be equivalent to the shales overlying the first Venango oil sand, which, according to the writer's classification, are Chemung. Mr d'Invilliers gives as the generalized thickness of Pocono in Center county 625 feet, and reports the section as consisting along the Allegheny plateau

* I. C. White: G 7, p. 43.

† Geology of Lycoming and Sullivan counties (G 2), 1880. Andrew Sherwood, p. 16; Franklin Platt, pp. 105, 107, 127.

‡ Franklin Platt: Rep. of Prog. in Bradford and Tioga counties (G), 1878, pp. 121, 127.

§ H. M. Chance: Geology of Clinton county (G 4), 1880, pp. 98, 125, 126.

mostly of white and gray sandstones, sometimes holding rounded pebbles and frequently showing bands of greenish and reddish argillaceous beds. The sandstones are fine grained and thin bedded.* Here the lower beds are increasing in importance.

Mr Sanders's section, in Blair county, south from Center, makes the Pocono 1,241 feet thick, but he has included about 350 feet at the bottom clearly belonging to the Catskill, so that the thickness is about 900 feet, of which the upper two-thirds is a practically continuous gray, current-bedded sandstone, broken only by two shale beds, one 3 and the other 20 feet thick.† No coal is reported from the Blair county Pocono; the Tipton coal of that county belongs to the Coal Measures, as originally asserted by I. C. White, and not to the Pocono. Still farther south, in Bedford county, and about 10 miles eastward from the face of the plateau, Stevenson found that the Pocono can not exceed 920 feet, and suggested that the interval may contain some Catskill rocks. so that the thickness is approximately the same with that in Blair.‡ Mr O'Harra states that a little south from the Pennsylvania line, in Maryland, and not far off the strike from the Bedford locality, the thickness is but 258 feet, the rock being a grayish green flaggy sandstone, with some shale and some bands of conglomerate. He finds it but 30 feet thick in the gorge of the Potomac, where it is a gray cross-bedded sandstone, with a few widely scattered pebbles.§ Doctor White's detailed section in Maryland, along the Baltimore and Ohio railroad, where the Potomac emerges from the Allegheny plateau, shows about 1,150 feet of gray, cross-bedded, mostly flaggy sandstones, apparently free from conglomerates and red shales.||

The strip west from the front of the Allegheny plateau.—Returning to the north outcrop, the first Pennsylvania survey found in Tioga county (adjoining Bradford at the west) 300 feet of sandstones underlying the shales and sandstones of the Mauch Chunk (Umbral), divided midway by 5 feet of shale, and showing near the bottom a calcareous bed.¶ Doctor White estimates 573 feet as the extreme possible thickness for Pocono near Blossburg, in this county, but the estimate is not given with assurance, as exposures below the Mauch Chunk are wanting.** In view of observations in counties on both sides of Tioga, the interval appears to be excessive. In Potter county (west from Tioga) Mr Ashburner finds the extreme thickness for Mississippian not more than 400 feet,

* E. V. d'Invilliers: Geology of Center county (T 4), 1884, p. 122.
† R. H. Sanders: Geology of Blair county (T), 1881, pp. 13, 23.
‡ J. J. Stevenson: Geology of Bedford and Fulton counties (T 2), 1882, p. 70.
§ C. C. O'Harra: Allegany county, pp. 109, 110.
|| I. C. White: Notes on the Geology of West Virginia. Proc. Am. Phil. Soc., vol. xix, p. 443.
¶ H. D. Rogers: Geology of Pennsylvania, vol. ii, p. 520.
** I. C. White: G 5, 1881.

and he regards the upper 70 feet as unquestionably Mauch Chunk.* Some of the lower portion is Chemung, but that is unimportant here, as the thickness suffices to show the rapid decrease westward along the northern outcrop in Pennsylvania. In Potter county is found the most easterly line at which Doctor White's Shenango sandstone, the sub-Olean conglomerate of other authors, has been recognized fully ; but the reader who has followed these notes can have no difficulty in finding traces of it along the northern outcrop in the persistent sandstone, often conglomerate at the top of the Pocono, which is so characteristic that Doctor White when he reached the northeastern outcrop was almost ready at once to identify it with his Shenango.† From Potter westward its pebbles are flat like those of the persistent Chemung conglomerates, but it becomes conglomerate westward. In Clinton county it is only coarse, while in Cameron (west from Clinton) and in western Potter, at the north, it is conglomerate.

McKean county adjoins Potter at the west. There Mr Ashburner finds this Shenango sandstone, 40 feet thick, sometimes largely conglomerate, at others largely hard, massive, fine grained ferruginous sandstone. His lower Pocono, which is the lower portion of Doctor Chance's upper Pocono, is said to be 150 to 190 feet thick, extending downward to the Marvin Creek Limestone, which contains Chemung fossils. This may be the persistent limestone already referred to as found in Tioga county. Mr Ashburner regards it as equivalent to that occurring at the same horizon in Elk county (south from McKean) and to Doctor White's lower Meadville limestone of Crawford county.‡

In Cameron county (south from McKean and west from Clinton) Mr Ashburner finds the Pocono varying from 745 feet in the extreme middle east to 470 feet in the extreme northeast, but for the most part the sections are too imperfect to justify definite conclusions respecting either thickness or boundaries. It is sufficiently clear, however, that at 50 to 60 feet below the Pottsville sandstones begin, and that some of them are coarsely conglomerate. Fragments of the Shenango sandstone (sub-Olean) occur in northern Elk, west from Cameron. A fossiliferous limestone occurs at 200 feet below the Pottsville. For this county the Pocono is given as from 500 to 610 feet, including some fossiliferous limestones.§ The discrepancies between the descriptions by Mr Ashburner and those by Doctor Chance in G 4 are apparent rather than real. Doctor Chance has presented the conditions more methodically

* C. A. Ashburner: Geology of Potter county (G 3), 1880, p. 104.
† I. C. White: G 5, p. 66.
‡ C. A. Ashburner: Geology of McKean county (R), 1880, pp. 64–69.
§ C. A. Ashburner: The township geology of Elk and Forest counties (R 2), 1885, pp. 18, 19, 105, 247.

and with a clearer conception of the relations. The statement of facts is practically the same in both reports.

No measurements are available for Clearfield and Jefferson counties, lying south from Elk and Forest, and nothing can be obtained until one reaches the Conemaugh gaps through the Viaduct, Laurel, and Chestnut hill, and the Youghiogheny gaps through the same anticlines farther south. In the Conemaugh gap through Chestnut ridge, Westmoreland county, Stevenson found the Pocono a massive sandstone, 443 feet thick, broken only by two shale beds, 3 and 10 feet respectively. Much of it is current-bedded, and many layers, especially toward the bottom, are conglomerate, with pebbles as large as a plum and often flat. A 4-inch bed of impure limestone was seen near the middle. The thickness in the Youghiogheny gap through the same ridge is not far from 375 feet, the rock being mostly fine grained sandstone, though layers of conglomerate are numerous, as on the Conemaugh in the bottom 60 feet. In the Youghiogheny gap through Laurel ridge the thickness appears to be not more than 300 feet.* The conglomerate layers with small flat pebbles show a singular parallelism at exposures on both rivers as well as at several localities on both sides of Chestnut ridge along the National road in Fayette county.

Doctor White records several sections in northern West Virginia. In southeastern Preston county, along the Baltimore and Ohio railroad, under the Viaduct axis of Pennsylvania—the Briery mountain of West Virginia—he finds 566 feet of sandstones and shales with an impure limestone, 1 foot thick, at 150 feet from the bottom, this possibly representing the thin limestone of the Conemaugh gap through Chestnut ridge. The section is interesting as exhibiting a structure very familiar in the oil-well records in the interior of the state. Somewhat condensed it is

	Feet
1. Sandstone	120
2. Mostly shale	115
3. Sandstone	75
4. Shales, shaly sandstone, and sandstone	105
5. Limestone, impure	1
6. Mostly shale	150

Number 2 contains 10 feet of sandstone, number 4, 12 feet of apparently massive sandstone, and number 6, 18 feet, besides beds of shaly sandstone and sandy shale.† The Laurel Hill anticline decreases south-

* J. J. Stevenson: Report of progress in the Fayette and Westmoreland district, part i, 1877. (K 2), p. 291. The same, part ii (K 3), 1878, pp. 54, 77, 105.

† I. C. White: University of West Virginia Catalogue, 1882–'83, p. 50.

ward, so that where cut by Cheat river, in Preston county, it brings up only the topmost 50 feet of the Pocono, which is a massive sandstone. About 425 feet of Pocono is above the river in its gap through Chestnut ridge, in the same county. There it appears to be wholly sandstone, massive and pebbly at the top, where it is current-bedded, but hard and flaggy below.*

The western counties of Pennsylvania.—Returning now to the northern border, Mr Carll says that the Shenango (sub-Olean) is not always conglomerate in Warren county (west from Potter and north from Forest). He finds at Warren the Shenango 30 feet thick, resting on 53 feet of shales and sandstone, containing some fossiliferous beds, below which are shales and sandstones for 363 feet. Near the same place Mr Randall found 40 to 50 feet of Shenango resting on an equal thickness of buff, sandy shales, succeeded by sandstones and shales, about 250 feet, to a flat pebble conglomerate, which is evidently the first Venango oil sand, the Upper Chemung conglomerate of Stevenson. Mr Randall says that the Shenango and the immediately underlying shales are fossiliferous, and suggests that the species show a mingling of Chemung and Carboniferous forms.† Here the lower transition beds and the Catskill have disappeared.

Passing over into Crawford county, on the Ohio line, one finds Doctor White's detailed studies, which make the section clear and prepare for the Ohio conditions. The Shenango sandstone, the topmost portion of the Pocono, is a flat pebble rock, 15 to 35 feet thick in Crawford and Erie counties. It has been traced by Doctor White eastward from the Ohio state line through Crawford, Warren, and McKean, and, farther south, from the same line across Mercer and Clarion. It is white, always sandstone, and becomes massive and coarser eastward. It shows notable variations in thickness, 15 to 35 feet in Crawford, while in southern Mercer, near Sharon, it is only 3 to 7 feet, though always retaining its character. It is pebbly near the Ohio line, but the pebbles are fine. The bottom layers become pebbly at Meadville, in Crawford. At Garland, in Warren, they are quite pebbly. At Warren, in the same county, the rock is pebbly throughout and 40 to 50 feet thick. At many places it contains fish remains.

Doctor White's Meadville shales underlie the Shenango sandstone, are 60 to 80 feet thick, and are divided above the middle by 6 to 18 inches of limestone. These shales are persistent also in Mercer and Venango counties. The limestone, Upper Meadville of White, is very

* I. C. White: Notes on the geology of West Virginia. Proc. Am. Phil. Soc., vol. xx, 1882, pp. 488–492.

† J. F. Carll: Geological report on Warren county (I 4), 1883, pp. 190, 298, 305.

fossiliferous, often simply a fish-bone conglomerate. Dr O. St. John regards the fishes as presenting the aspect of the lower Mississippian. Doctor White states that the molluscan remains are related to the Kinderhook, but he is inclined to regard the total evidence as pointing toward the lower Keokuk or upper Burlington. The Sharpsville sandstone underlies the Meadville shales; it contains in the lower part a flinty limestone, non-fossiliferous in Crawford county, but fossiliferous at Garland, in Warren county, and at Tidioute, in Venango, where it is full of distorted shells, among which *Spirifer disjunctus* or a closely allied form is most abundant.

Below the Sharpsville are the Orangeville and the Oil Lake group, the latter being equivalent to the Berea sandstone of Ohio. The total thickness is approximately 440 feet, and the whole is referred to the Pocono.*

Doctor Chance has summarized the variations of the "upper or gray Pocono" as they appear along the northern border in Pennsylvania. From the edge of the Allegheny plateau until one reaches western Clinton county, the sandstones are fine grained, foliated and hard, gray or greenish gray. In that county from 60 to 80 per cent is sandstone, the rest is sandy shale; but westward, along the lines followed by him, the rocks become more shaly and less arenaceous, until more than half of the hard sandstone below the Shenango has been replaced by olive and gray shales. The thickness of the Pocono averages not far from 400 feet in Clinton, Cameron, Elk, McKean, Warren, and Mercer counties, and the series is regarded by him as equivalent to the Waverly of Ohio.†

Southward from Mercer and Venango counties the anticlines do not bring the Pocono to the surface, so that, in the southern counties, one is dependent upon oil-well records, many of which have been tabulated by Mr Carll. Here quotations are made only from his latest Pennsylvania reports, which give the essential facts for Beaver, Butler, Allegheny, Washington, and Greene counties, the last three being west from Westmoreland and Fayette, in which are the Conemaugh and Youghiogheny gaps, already referred to as offering good exposures of the Pocono.

The Shenango sandstone is followed easily in the records, but apparently the Meadville shales and limestone become irregular at no considerable distance southward, and sometimes are replaced by sandstone. In northern Mercer county the Shenango is 15 feet thick, with the upper Meadville limestone at 25 feet below it; 30 miles southeast, at Edenburg, on the western border of Clarion county, a record shows that the sandstone is 64 feet, resting on 283 feet of shale, extending downward

* I. C. White: Geology of Erie and Crawford counties (Q 4), 1881, pp. 77-96.

† H. M. Chance: G 4, p. 98.

to the Upper Chemung conglomerate or first Venango oil-sand; while in Brady township of Butler, about 25 miles southwest from Edenburg, sandstone is 90 feet, divided midway by 10 feet of shale; at Pittsburg, about 30 miles south from the last, the sandstone is 170 feet, with 10 feet of shale at 20 feet from the bottom. Here one is 45 miles due west from the Conemaugh gap through Chestnut ridge, where the upper plate of the Pocono is a sandstone 250 feet thick. At Murraysville, Westmoreland county, 15 miles east from Pittsburg, the sandstone is 200 feet thick resting on shales. The record in Mount Pleasant township of Washington county shows 106 feet of white sandstone, separated by 22 feet of shale from 11 feet of fine white sand, below which are shale and sand for 112 feet, a total of 251 feet; at Washington, in the center of the same county, the record is incomplete; it gives sandstone 120 and 30 feet, separated by 2 feet of shale; but at Waynesburg, in Greene county, the record shows 230 feet of white sandstone underlying the Mauch Chunk.* It is quite possible that the sandstone in the borings may represent the Shenango and the Sharpsville, and that the intervening shale, so irregular, may be the Meadville. Where thin it may have been neglected by the driller. The records in West Virginia bear out this suggestion.

Along the northern and western outcrop in Ohio.—The Shenango sandstone has been followed by Doctor White into Trumbull county of Ohio, where it is about 15 feet thick and rests on 80 feet of Meadville shales. Professor Orton regards the Logan sandstone of Ohio as the Shenango sandstone, but includes also in the equivalence the overlying Shenango shales of White, which, as will appear in the second chapter, must be considered with the Mauch Chunk.

The Logan, in Ohio, is double, sandstone above and conglomerate below, at the typical localities. Followed into Ohio from Pennsylvania, the rock becomes finer, the sandstone becoming shale and the conglomerate, sandstone. In the counties of Knox, Holmes, Richland, and Cochocton, the sandstone is represented by the Olive shales of M. C. Read, which are upward of 200 feet thick, but farther south the mass becomes a fawn-colored, even-bedded, fine grained sandstone. The conglomerate gains in coarseness westward and southward, being a coarse rock in Wayne, Holmes, Cochocton, Knox, Licking, Fairfield, Hocking, Vinton, and Ross counties, which, as Professor Orton observes, mark "the northwestern arc of the sea boundary in Sub-Carboniferous time." The conglomerate is not always continuous, there being usually, as Professor C. L. Herrick has shown, two beds of conglomerate separated by layers of fine sand-

* J. F. Carll: Ann. Rep. second Geol. Surv. Penn. for 1886. These notes have been taken from the plates in Mr Carll's discussion, forming part ii of this annual report.

stone or even of shale. The pebbles are usually flat, small, and of practically uniform size. Southward from Ross county, along the western outcrop, the rock is less coarse and it ceases to be conglomerate before reaching the Ohio river, where it is the upper portion of the Kentucky Knobstone. The Logan rests upon the Cuyahoga shales of Orton, varying from 150 to 400 feet, with the Buena Vista sandstone at the base, a persistent bed, identified with the Sharpsville of White and continuous from the Pennsylvania line around the outcrop to the Ohio river at Buena Vista. Below this is the Berea shale, regarded as the equivalent of White's Orangeville, and at the base is the Berea grit, continuous from lake Erie to the Ohio river, 50 to 75 feet thick, a fine sandstone at the north, but somewhat argillaceous at the south. This ripple-marked sandstone is thought by Professor Orton to be equivalent to the upper part of White's Oil Lake group.* This rests on the Bedford shales. Herrick has shown that the Logan does not extend so far northward as do the Cuyahoga shales.

The eastern outcrops in the Virginias.—Let us return to the east and follow the outcrops southward from the Potomac river.

Professor W. B. Rogers, in his " Reconnaissance," states that the Pocono (Vespertine) contains coal beds in Berkeley, Frederick, Shenandoah, Rockingham, Augusta, Botetourt, and Montgomery counties of Virginia, but he gives no details respecting the character or thickness of the rocks.

Professor Fontaine regards the Pocono (Vespertine) of Augusta and Rockingham as triple—a lower division consisting of sandstone, a middle division of sandstone and shales with coal beds, and an upper division consisting mostly of red shale and sandstone. He assigns to the lower division about 400 feet of sandstone, gray below and white above. No estimate of thickness of the higher divisions was made, as exposures are imperfect and the region very seriously disturbed.† Mr Darton for the same region, as well as a part of Pendleton county of West Virginia, assigns to the lower division 300 feet of white or buff quartzite, sometimes slightly conglomerate. His upper division—sandstones, shales, and coal beds—has an extreme thickness of 450 feet. It shows no shales on North mountain, or on Shenandoah mountain along the West Virginia boundary. Farther north on the latter mountain the whole thickness is about 700 feet.‡

Messrs Taff and Brooks find little more than 100 feet of Pocono in Randolph county, West Virginia, nearly 30 miles west from Shenandoah mountain.§

* E. Orton: Ohio Survey Reports, vol. vii, 1893, p. 28 et seq.

† W. M. Fontaine: Am. Jour. Sci., vol. xiii, p. 116 et seq.

‡ N. H. Darton: Staunton folio, U. S. Geological Survey, 1894.

§ J. A. Taff and A. H. Brooks: Buchhannon folio, U. S. Geological Survey, 1896.

Professor Fontaine found the Pocono near Lewis tunnel, on the Greenbrier river, about 6 miles east from White Sulphur Springs, West Virginia, as well as at Caldwell station, 12 miles farther west. At the latter locality 250 feet of red crumbling marlites underlie the Greenbrier or Mauch Chunk limestone. These had been referred by Professor W. B. Rogers to the Mauch Chunk (Umbral), but Fontaine prefers to place them in the Pocono. Below these he finds 290 feet, representing his middle division of Augusta and Rockingham, consisting mostly of sandstones, in which are many carbonaceous streaks—not coal beds, as no fireclay is associated with them. But at Lewis tunnel this division is 350 feet, with irregular coal beds underlain by fireclays. Below this is a coarse, more or less conglomerate sandstone, 80 feet thick, resting on transition beds 500 feet, consisting mostly of yellow flaggy sandstones, weathering brown. The whole thickness is 1,160 feet.* This is on the line with the Augusta locality.

Beyond the Greenbrier river, owing to the rapid development of faults, the Pocono extends farther eastward than it does at the north, and the area of Carboniferous reaches to East or Peters mountain, while toward the southeast is the narrow strip along Brushy mountain, in Bland, Smyth, and Washington counties; the similarly narrow strip along Little Walker mountain, in Montgomery, Pulaski, Wythe, and Smyth counties, as well as some petty outliers within the Great valley in Catawba and Price mountains of Montgomery and in Pulaski and Wythe counties. The information respecting Monroe county of West Virginia beyond East mountain is very scanty, as is also that respecting Catawba mountain.

Fontaine made a careful study of Price mountain, where he measured 1,090 feet of red shales above his middle division, but made no detailed measurement of the lower divisions. The greater part of this mass belongs to the Mauch Chunk, which here has no limestone. Two coal beds, 2 and 6 feet respectively, are mined here.† Stevenson visited Price mountain, as well as the little area east from Wytheville, on the Norfolk and Western railway, but made no measurements. His conclusions respecting the shales agree with those of Fontaine.

Little Walker mountain is known as Brush mountain in Montgomery county. There Professor Fontaine assigned 930 and 670 feet to his lower and middle divisions, but did not obtain any measurement for the upper division. Stevenson succeeded in making a section on New river at 4 or 5 miles southwest from Fontaine's locality. He cuts off most of the lower division, placing it in the Devonian, and practically draws the line under the conglomerate sandstone, 30 to 80 feet thick,

* W. M. Fontaine: Am. Jour. Sci., vol. xiii, pp. 44–48.
† W. M. Fontaine: Op. cit., p. 119.

which underlies the middle or coal-bearing division. The section shows only shales and sandstones for about 1,700 feet, as determined from the dip, of which the bottom 700 feet are assigned to the Pocono.* Coal beds have been opened at many places along little Walker, in Montgomery, Pulaski, and Wythe counties. Thirteen beds are reported within a vertical distance of 400 feet in western Wythe, but only the lowest three become important economically. The thickness varies, as the beds have suffered much from compression, and in many cases the shales have been thrust into the coal. The dying of this fault throws out the Mississippian at a little way over in Smyth county.†

The great Saltville fault has preserved the Mississippian in southern Bland (north from Wythe), as well as in Smyth and Washington, and beyond for several miles in Tennessee. The exposures in Bland were not such as to admit of measurement. The coals continue into Smyth and the hard sandstone, the "Quarry" of Wythe county, the 80-foot rock of Lewis tunnel, underlies them. The thickness in Smyth was estimated at 500 feet, but in this were included rocks which afterward were referred to an earlier period. A noteworthy change begins in eastern Smyth, for there impure limestones appear in the shales and the passage to the overlying limestones is very gradual.‡ This change is very rapid toward the southwest, for when one has reached the middle of Washington county, adjoining Smyth, he finds the Pocono so linked with the great limestone mass that the separation can be made only with great difficulty.

It is possible that the lowest coal bed may be persistent thus far, for coal is said to have been digged at low water in the Holston river, near Mendota. The Pocono here is the Protean or lower division of Safford's Silicious group and the lower division, the great sandstone, is evidently a part of the Grainger shales of Mr M. R. Campbell, which carry Devonian fossils. In Wise county, about 40 miles west, the Pocono is about 150 feet thick on the waters of Powell river, where it consists of more or less calcareous sandstones with some shale.§ At probably 15 or 20 miles northwest in Whitely county, of Kentucky, where the Pine Mountain fault brings these rocks up, the thickness is estimated at fully 150 feet by Professor Crandall.||

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* J. J. Stevenson: A geological reconnaissance of Bland, Giles, Wythe, and parts of Pulaski and Montgomery counties of Virginia. Proc. Amer. Phil. Soc., vol. xxiv, 1887, pp. 105, 106.

† J. J. Stevenson: Op. cit., pp. 78, 79.

‡ J. J. Stevenson: Notes on the geological structure of Tazewell, Russell, Wise, Smyth, and Washington counties of Virginia. Proc. Amer. Phil. Soc., vol. xxii, 1884, pp 135, 143.

§ J. J. Stevenson: A geological reconnaissance of parts of Lee, Wise, Scott, and Washington counties, Virginia. Proc. Amer. Phil. Soc., vol. xix, 1881, pp. 242, 259.

|| A. R. Crandall: Geological Survey of Kentucky, Geology of Whitely county and part of Pulaski county.

The Pocono under West Virginia.—The oil-well records preserved in Doctor White's report on the geology of West Virginia exhibit the variations of the Pocono under cover in that state.

The northern tier of counties consists of Monongalia and Marion at the east, Wetzel and Tyler at the west along the Ohio river. In northern Monongalia near the border of Greene county, Pennsylvania, the section is in contrast with records from the latter county, for a well shows

	Feet
Sandstone	150
Shale and sandstone	160
Sandstone	100

a total of 410 feet, the middle containing 125 feet of shale. In a neighboring well the upper sandstone is 173 feet, with another sandstone of 55 feet at 55 feet below it. The records in Marion county are mostly incomplete, usually giving only the upper plate, which varies from 142 to 168 feet, but in one well the driller reports 50 feet of limestone below this plate, while at 40 feet lower there begins a mass of shale and sandstone 195 feet thick. In western Marion the thickness of the sand is given as 140 feet, but just over the line in Wetzel it is reported to be 250 feet, while elsewhere in that county it varies from 127 to 192 feet. The complete record of one well shows, however, that these variations may be due in some degree to the caprice of the driller, who may end the record for the "Big Injun" at the base of the upper plate or may continue it until the first thick bed of shale has been reached; for in that well the driller reports two beds of sandstone, 151 and 150 feet, separated by 4 feet of shale. There is, however, a distinct individuality about the upper plate, that known in West Virginia oil districts as the "Big Injun." In complete records of wells in Marion, Monongalia, Wetzel, and counties of the northern "panhandle" of the state, a shale of varying thickness separates this upper plate from one below, known in some localities as the "Squaw sand." In Monongalia the upper plate is from 150 to 173 feet, the shales from 55 to 57 feet, and the lower plate from 35 to 100 feet. In Marion the upper plate is 130 to 140 feet; one record gives 30 feet for the shale, and there is no record for the "Squaw."

Northward from Wetzel, in the northern "panhandle," which is west from Greene, Washington, Allegheny, and Beaver counties of Pennsylvania, one finds the two sandstones differentiated in most of the records. At Moundsville, in Marshall county, the Big Injun is 165 feet, resting on 50 feet of shale; at Wheeling, in Ohio county, 139 feet, with 45 feet of black shale between it and the Squaw, 25 feet thick; at Wellsburg, Brooke county, one finds Big Injun 140 feet; Shales, 50 feet; Squaw, 50

feet; but near New Cumberland, in Hancock county, the Big Injun is 95 feet thick, with 350 feet of shale below it. Here one is so far north, alongside of Beaver county, Pennsylvania, that it is difficult to resist the conclusion that the section represents the Shenango-Logan sandstone resting on the Cuyahoga shales; so that the upper plate is evidently the Shenango sandstone of White; the Shale, his Meadville, and the Squaw his Sharpsville.

In this connection it may be well to introduce for comparison the record of a well at McDonald's station, in northern Washington county, Pennsylvania, about midway between Pittsburg and Wellsburg, on a west-southwest line. The record is exceptionally satisfactory, in that the measurements were made at intervals of 1 to 3 feet, and additional precautions were taken to confirm rope measurements by tape measurements at intervals of 15 to 60 feet. At each measurement the drillings were tested with acid. The grouping by Doctor White is

	Feet
"Big Injun sand," all sand except in 17 feet near bottom, no trace of limestone	237
Shales, white, gray, black, a little sandstone	88
"Squaw sand," 9 feet of shale near middle	42
Shales, black and gray, some sandy beds	201
Sand	29
Total	617

From the "Squaw" to the first Venango sand in this record is 333 feet. This section is greatly in contrast with those at Pittsburg and Wellsburg. At the former the upper sandstone is 140 feet, separated by 10 feet of shale from the lower bed of 20 feet, which rests on 115 feet of shale; at the latter the Big Injun is 140 feet, the Shales 50 feet, the Squaw 50 feet, resting on 400 feet of blue shale. It is equally in contrast with the section at Mount Pleasant, a few miles south from McDonalds, where the Big Injun may be taken as 133, slate 22 feet, Squaw 11 feet, shales and irregular sandstones 367 feet, and the total distance from the bottom of the Mauch Chunk to the first Venango sand is 671 feet as against 720 feet at McDonalds. The chief concern for us, as will be seen in the second section of this chapter, is with the Big Injun or upper plate, but it is noteworthy that the Crawford County section is recognizable as far south as southern Pennsylvania.

Returning to the south and crossing Wetzel county, one reaches Tyler. Here, as in several other counties, the lower portion of the Greenbrier (Mauch Chunk) limestone is absent, while the sandstone overlying it is persistent, and therefore rests directly on the Shenango, from which it can not be separated easily. This is the "Keener" sand of the drillers,

to which more detailed reference will be made in chapter ii. At Alva, in Tyler county, the two sandstones are 161 feet, with no record above or below for many feet. Few of the Tyler records go below the Shenango or Big Injun, as that is the oil-bearing rock in the Hebron and Sisterville pools of that county. In one well near Little Mills the Big Injun is 79 feet, separated by 20 feet of black shale from the Squaw, which is 20 feet. The Keener varies from 15 to 19 feet.

In Pleasants county, which extends along the Ohio river beyond Tyler, the Mauch Chunk is wanting and the Pocono is continuous with the overlying Pottsville, the records showing from 330 to 375 feet of sandstone for the two formations.*

The next tier of counties at the south consists of Harrison, Doddridge, Ritchie, and Wood, the last reaching the Ohio river.

The records in Harrison begin on the western side, almost on the strike from Mannington, in Marion county, and show a condition not easily explained. It is true that near Mannington limestone is reported below the Big Injun, but in Harrison the sandstone is very thin, 20 to 40 feet, with a great thickness of limestone below it within the Sardis Pool district. The same condition is reported from the Ten-mile district, a few miles southwest from the last; but in southern Harrison, within the Jarvisville district, the records give no information beyond the fact that the Big Inj n is still thin, 47 to 80 feet, the underlying rocks being unrecorded. Doctor White lays emphasis on this change in the Big Injun as explaining the absence of oil and gas.

In Doddridge county, near Sedalia, only 10 miles west from Sardis, the Big Injun is sandstone, 102 feet, with underlying rocks unrecorded. Three or four miles northwest, at Center Point, the Keener is separated occasionally and is given in one record as 13 feet, but as it is separated from the Shenango only by a very thin shale, the two rocks are recorded usually as a continuous sandstone. As thus constituted, the Shenango in northern Doddridge averages about 115 feet and is separated from the Squaw or Sharpsville sandstone by 34 to 40 feet of shale, reported in one record as black. The conditions observed in Tyler, Wetzel, and the northern counties are reproduced here, though the Shenango is thinner. Farther south, in eastern Doddridge, near the Baltimore and Ohio railroad, the Shenango is but 79 feet, with only "shales, sand, and shells" below it for 148 feet. In south central Doddridge, 8 miles from the railroad, the thickness is given as 195 feet, with unrecorded rocks for 583 feet below; but at Oxford, 8 miles farther west, near the line of Ritchie

* I. C. White: Geology of West Virginia, vol. i, 1900. Monongalia county, p. 235; Marion county, pp. 245, 347; Wetzel county, pp. 339–349; Panhandle, pp. 362–369; Tyler county, pp. 336, 338, 355–360; Pleasants county, p. 353; McDonalds, p. 228.

county, one finds evidence that the Shenango is breaking down, for the sandstone is but 24 feet, with unrecorded rocks for 342 feet below it.

In southern Ritchie, about 3 miles south from Oxford, the Big Injun is given as 47 feet, while at 12 miles northwest, on the railroad and nearly 25 miles west from Long Run, eastern Doddridge, the sandstone is 54 feet, with no record below for 347 feet. In north central Ritchie, within the Whiskey Run district, about 5 miles southwest from the Hebron district, in Tyler county, the sandstone is thinner than in the latter district and much thicker than in southeastern Ritchie, though still much as in northern Doddridge, two wells giving 70 and 73 feet, the Keener being included in both. The records are nearly complete in central Ritchie, near Harrisville and Cairo. Midway between Whiskey run and Cairo the Big Injun is reported as 140 feet, with 222 feet of shales below it; but at Cairo, on the railroad, 4 miles southwest from the last, it is only 97 feet, while at Harrisville, 3 miles east from Cairo, it is 102 feet. No records in southwest Ritchie pass through the Shenango, but a record at Burning spring, in Wirt county, 12 miles south-southwest from Cairo' gives the Big Injun as 50 feet, with 385 feet of gray shale below it. This locality is barely 10 miles farther south than is Oxford, in Doddridge county. On the western side of Ritchie, north from the Baltimore and Ohio railroad and not more than 15 miles due north from Burning spring, the Big Injun is given as varying from 121 to 147 feet, in each case resting on a great mass of shale. In the former well the mass is white sand throughout, but in the latter the bottom 34 feet of sandstone is separated from the upper plate by 14 feet of shale. Doctor White identifies the lower plate with the Squaw. This increase northward accords with the Tyler conditions.

Passing over into Wood county, one finds in the Hendershot district 200 feet of Big Injun, with limestone below it. Doctor White suggests that some of the sandstone may belong to the Pottsville, as the Mauch Chunk is absent westward. Be this as it may, a record obtained a little farther eastward in the same district shows 222 feet of sandstone underlying the Mauch Chunk and resting on a great mass of shale. At Parkersburg, on the Ohio, the thickness is 205 feet, with apparently no shale division. At Marietta, on the Ohio side of the river, according to Professor Orton, the sandstone is 335 feet thick, resting on the Cuyahoga shales; but much of this sandstone must be referred to the Pottsville, as the Mauch Chunk is absent. At Macksburg, Noble county, Ohio, 20 miles north from Marietta, 214 feet of pebbly sandstone overlie the Cuyahoga shales.* Professor Orton says that the Logan (Shenango)

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*I. C. White: Op. cit. Harrison county, pp. 248–254; Doddridge county, pp. 321–333; Ritchie county, pp. 300–321; Wirt county, p. 262; Wood county, pp. 285–298.

sandstone is usually about 200 feet thick in southeastern Ohio, as shown by well records.*

The next tier of counties consists of Lewis and Braxton at the east, Gilmer, Calhoun, Roane, Jackson, and Mason, the last extending along the Ohio river beyond Wood.

Lewis is south from Harrison. Here are two records, one at the eastern edge at about 25 miles west from the Pocono outcrops in Rich mountain of Randolph county, West Virginia, and the other about 20 miles west on the western line of the county. In the eastern well one finds underlying the greatly thickened Greenbrier (Mauch Chunk) limestone and separated from it by 50 feet of shale, 215 feet of sandstone, which in view of the conditions on Rich mountain must be regarded as the Shenango. At Vadis, on the western edge of the county, the thickness is 196 feet, while immediately over the Doddridge line it is 152 feet, considerably more than in northern Doddridge, but less than in the south central part of that county. A well bored near Sutton, in Braxton county, 30 miles south-southwest from that in eastern Lewis, shows no sandstone whatever at the Shenango horizon, there being for 800 feet below the Mauch Chunk limestones nothing but shale except 5 feet of sandstone about midway in the mass. Glenville, in Gilmer county, is 10 miles west of south from Vadis, in Lewis county, and 20 miles west of north from Sutton. Evidently no sandstone occurs here below the limestone, for the driller found nothing worthy of record until he had gone 629 feet below it; so that the conditions here are most probably the same as at Sutton, and very much such as one should expect from the southward decrease of the Shenango in Ritchie county, for at Glenville one is about 23 miles south from Oxford, where the Shenango sandstone is but 47 feet thick.

No records are given for Calhoun county, the next west from Gilmer; but one may recall the measurement at Burning spring, northwest from Glenville, where the sandstone is but 50 feet. This locality is 15 miles north from Spencer, in Roane county, which is 30 miles south of west from Glenville. There the sandstone is missing, being either gone or more probably replaced by shale, but at 11 miles southwest from Spencer, in the same county, it reappears, clean, white, and 45 feet thick. This locality is about 40 miles west from the Sutton well. The next record is at Ravenswood,† on the Ohio river, in Jackson county, where the sandstone is 147 feet, and the underlying shales are more or less sandy. At Letart, on the Ohio, in Mason county, 12 miles west from Ravenswood,

* Edward Orton: Ohio Survey reports, vol. vii, p. 379.

† Ravenswood is 25 miles from Spencer, 30 from Burning spring, and 25 miles west from Parkersburg.

159 feet of sandstone underlie 65 feet of shale and sandstone and rest on 270 feet of Cuyahoga shale. The same condition is found opposite Gallipolis, 12 miles southwest from Letart, where the sandstone beds begin at 10 feet below the Mauch Chunk.*

Kanawha county is south from Roane. A well at Burning spring, 40 miles south from Spencer and somewhat more than 50 miles southwest from Sutton, has no sandstone under the Mauch Chunk (Greenbrier) limestone for more than 1,000 feet, aside from a 2-foot layer at 237 feet, showing the continuance of the shale southward; but on the Ohio river, at Central City, in Cabell county, 50 miles west from Burning spring and 30 miles south from Gallipolis, the Shenango-Logan is 177 feet, separated from the Mauch Chunk above by 28 feet of shale and resting on 370 feet of Cuyahoga.†

A well in southern Lincoln county at about 35 miles southwest from the Burning spring and the same distance southeast from Central City, shows no sandstone for 260 feet below the Mauch Chunk limestones. Near Dingess, 10 miles southwest from the last, the more or less sandy red rock observed below the limestone at the Burning spring, as well as in Lincoln county, has become a hard, red sandstone, 94 feet thick, while at 10 miles farther southwest, on the Sandy river, opposite Warfield, Kentucky, only shale underlies the limestone; so also in another well at a few miles farther south only shale occurs for more than 400 feet below the limestone. The consolidation near Dingess appears to be merely local.‡ Evidently the area in which the Pocono is represented only by shale is broad and far-reaching southward.

The eastern outcrops in Tennessee and Alabama.—The Pocono is followed with difficulty by means of lithological characters in the southeasterly outcrops southward from the Virginia line, but the conditions along the edge of the Cumberland plateau become clearer as the outcrop is followed south, for the Pocono is in part the Protean division of Safford's Silicious group. The lower portion of the Pennsylvania Pocono, that below the coal beds in Virginia, decreased rapidly in the southwestern part of that state until it disappeared or was merged into the Grainger shales of M. R. Campbell.

Details are wanting in northern Tennessee; Safford's work there was incomplete, and the investigations of the United States geologists have been published in very small part; but midway in the state Mr Hayes describes the lower part of the Great Limestone mass as very cherty,

* I. C. White: Op. cit. Lewis county, pp. 255, 258; Braxton county, p. 270; Gilmer county, p. 260; Wirt county, p. 262; Roane county, pp. 264, 268; Jackson county, p. 284; Mason county, pp. 274, 282.

† I. C. White: Op. cit. Kanawha county, p. 272; Cabell county, p. 275.

‡ I. C. White: Op. cit. Lincoln county, p. 280; Mingo county, pp. 276–279.

enabling us to recognize the Protean of Safford as distinguished from the more calcareous Lithostrotion bed above. This Protean is traceable easily into Alabama, where it is the Lauderdale of McCalley and extends far southward beyond the Grainger, resting for a great part of the distance on the still lower Chattanooga shales. In the southeasterly exposures it becomes very thin and disappears before southern Shelby county of Alabama has been reached. But much farther north it seems to have been lost in the overlying Tuscumbia, equivalent to Safford's Lithostrotion. The Lauderdale is sharply defined along Wills valley in front of the Cumberland plateau as well as in Browns valley, within that pleateau. It consists almost wholly of chert and disappears south, so that it is recognizable only with doubt in Bibb county of central Alabama.

The western outcrops in Alabama, Tennessee, and Kentucky.—On the west side of the plateau, the Lauderdale is practically the newest formation exposed in the northwestern three counties of Alabama, where it contains much limestone with much bedded chert, in this respect differing from the overlying Tuscumbia, in which the chert is usually nodular, rarely bedded. Its thickness varies from 175 to 225 feet.*

In Tennessee, Mr Hayes does not separate the Protean from the overlying Lithostrotion, but includes them both under the term Fort Payne, but his reference to the abundance of chert in the lower portion enables one to recognize the Lauderdale near the Alabama border.† Farther north, in White county, Professor Safford gives a section of the Protean, thus:

	Feet
Limestone, cherty	100
Limestone, without chert	30
Shaly rock	20
Limestone and chert	127
Total	277

Chert increases downward, so that in the bottom 100 feet there is merely a succession of chert beds separated by thin layers of crinoidal limestone. Northeastward from White county a marked change occurs, for in the next county the section is

	Feet
Sandstone	8
Blue limestone, coarse, fetid	45
Interval, much chert	216
Total	265

* For references to Mr McCalley's Alabama reports, see chapter ii, where the whole series as it occurs in that state is described. This is necessary because at many localities the separation of Lauderdale and Tuscumbia will remain impossible until after much closer study has been made.

† C. W. Hayes: U. S. Geol. Survey folios. Sewanee, 1894; McMinnville, 1895.

resting on the black Chattanooga shale. Farther north, near the Kentucky line, these rocks weather almost wholly into shale.* This statement agrees with that of Mr Campbell, who, near the Kentucky line, finds 350 feet of "Waverly" shales and limestones.†

The Protean covers much of Tennessee west from the Great Central valley. In a great part of the southern and western counties of this area it "is a stratified leached mass of soft pale yellowish or orange gray porous sandstone, which can be easily sawn or cut with an axe." In many places toward the center and south it is a pale blue fetid calcareous silicious shale carrying chert, but the chert is not persistent. This shale reaches into Lauderdale county of Alabama. In Hickman county and in the northwestern portion of the area the Protean is sometimes an almost continuous limestone, 150 feet thick.‡ This area is continuous with that of central Kentucky and of Indiana and its features have only an indirect bearing on the Appalachian.

The Waverly of the Second Geological Survey of Kentucky is the same with the Knobstone of Joseph Lesley and includes the Protean of Safford. It is the same with the Waverly of Ohio, and its lower beds cover a narrow space extending southwardly from the earlier beds rounding the southerly point of the Cincinnati uplift. The whole series is shown in a narrow strip eastward, continuous with that of Ohio.

At one locality in Clinton county, near the Tennessee line, Doctor Loughridge obtained the following Waverly section:

	Feet
1. Sandstones, more or less calcareous	95
2. Shaly rock	50
3. Sandstone with geodes	40
4. Green shale	4
5. Crinoidal limestone with flints	25
6. Shale with flint layers	49
Total	272

and resting on the black (Chattanooga) shale; but the section varies much, for elsewhere in this county Doctor Loughridge measured 376 feet.§ In these sections the whole interval from the Mauch Chunk to the Black shale is regarded as belonging to the Lower Carboniferous and as equivalent to the Waverly of Ohio. Mr Joseph Lesley in his general description of the formation says that it is separable into two divisions;

* J. M. Safford: Geology of Tennessee, 1869, pp. 339, 354, 356.

† M. R. Campbell: Standing Stone folio, U. S. Geol. Survey, 1899.

‡ J. M. Safford: Op. cit., pp. 339, 340, 341.

§ R. H. Loughridge: Report on geology of Clinton county. Geological Survey of Kentucky, 1890, p. 18.

the lower or larger portion is an olive mud rock, while the upper, also olive colored, is very largely a fine grained sandstone, many layers of which are excellent for building purposes, while others have been used for grindstones. The upper portion is characterized by a *Spirophyton* resembling that of the New York Cauda-galli grit.* The upper or sandy portion is the protecting cover of the "knobs" of eastern Kentucky. Professor Crandall's notes on Greenup and Rowan counties confirm Mr Lesley's statement, for he describes the Waverly as upward of 500 feet thick, consisting of fine grained sandstones and shales, with layers of good building stone at the bottom and at other horizons. This accords with Professor Andrews's description of the formation as it exists in southern Ohio and the adjacent portion of Kentucky. The Kentucky geologists did not think that the Ohio subdivisions can be recognized in their state. Professor Herrick's work, however, has removed much of the difficulty.

In Kentucky the mass grows more and more sandy northward, and all trace of limestone seems to be wanting near the Ohio river. It is evident that on this westerly side of the basin the conditions are like those described on the easterly side, and that the change from merely land detritus to calcareous rock begins in middle Kentucky as at the east it begins in southern Virginia, with little difference in the latitude.

GEOLOGICAL RELATIONS OF THE POCONO

We have followed the variations of the Pocono around the Appalachian basin and, by means of the oil-well records, under much of the interior, where the formation lies deeply buried. The characters are distinct throughout except in the northern outcrops of eastern Tennessee, where for 100 miles detailed information is wanting, though on both sides of that space the conditions are clear, the features at the south being those foreshadowed by the changing structure and composition in southwest Virginia.

We have seen that the great mass, as observed in Pennsylvania, retains its general characteristics and thickness into Virginia, in which state its upper portion becomes less coarse and more shaly until within 60 or 70 miles of the Tennessee border, where calcareous deposits appear, and the formation becomes closely related to the overlying limestone mass, while the lower portion, which has retained its detrital character, seems to be merged into the Upper Devonian, the Grainger shales of M. R. Campbell. The change continues southward in the upper portion, and the deposit becomes mixed calcareous and silicious, often chert. Along the

*Joseph Lesley: Fourth report on the geology of Kentucky, 1861, pp. 451, 452.

northern outcrop the thickness decreases rapidly westward from the area east of the Allegheny mountains, apparently in part from loss of the lower beds, until it becomes approximately 400 feet in Clinton and the adjacent counties, whence to the northwest outcrop in Pennsylvania the variation is insignificant. The character of the rock changes slowly in that direction. It is mostly sandstone, often coarse, along the north-easterly outcrop and easterly outcrop, though in the central east shales occur, one of which, midway in the mass, was found by Dr I. C. White to be richly fossiliferous. An impure limestone makes its appearance in the same relative position near Ralston, in the second basin of Rogers. Hodge describes it in Tioga county of the third basin, and speaks as though it were widely distributed, while later observers have found limestones in the adjacent counties of Elk, Warren, and McKean. Doctor Chance has shown clearly how the Pocono, after reaching its minimum Pennsylvania thickness of about 400 feet in the third basin, changes in composition westwardly, becoming more and more shaly below the Shenango sandstone, so that Doctor White's section, giving for the Pocono of Crawford and Erie a series of shales and sandstones with several thin limestones, is what one might expect to find in northwest Pennsylvania. The Pocono holds an impure limestone in the Chestnut Hill gaps of southwest Pennsylvania and northern West Virginia, where the mass is once more a sandstone.

Along the westerly outcrop in Ohio one finds the same general conditions as in northwest Pennsylvania, the sandstone on top with shales and irregular limestones below. Southwardly the limestones disappear and do not reach into northern Kentucky, but midway in that state calcareous beds appear, as at the southeast in southern Virginia, increasing southward until they become important in Tennessee, while in northwest Alabama one finds only limestone and chert. The thickness diminishes southward from nearly 500 feet at the Ohio river to 175 feet in northern Alabama, and the whole disappears finally before one reaches the middle of that state. Apparently the thinning toward the south is due to the gradual loss of the lower members—a continuation of the conditions observed in the upper Devonian.

The physical geography is discussed later on; here must be considered only the place of the Pocono in the geological column.

The Pocono of Pennsylvania, Ohio, Kentucky, and Virginia has been regarded by most geologists as Lower Carboniferous throughout. The Pocono of the eastern outcrops in Pennsylvania has been accepted as the equivalent of that in the western counties, as though the westward decrease were due merely to lessened thickness in each of the subdivisions,

It must be clear, however, to the reader who has followed the preceding summary that the loss in thickness is due very largely to disappearance of the lower members of the section, as is the case also southward from central Kentucky and southern Virginia, so that in Alabama and much of Tennessee only the uppermost beds remain. A new correlation appears to be necessary.

As already stated, Dr I. C. White's work first made clear the relations of the Pocono divisions in northwest Pennsylvania. His Shenango shales, Shenango sandstone, and Meadville shales, down to and including the upper Meadville limestone, are undoubtedly Lower Carboniferous, while the underlying divisions—the lower part of the Meadville shales, the Sharpsville sandstones, the Orangeville shales, and the Oil Lake group—are evidently later Devonian. Doctor White obtained from the upper Meadville limestone an abundant fauna, vertebrate and invertebrate, which was submitted to Professors Worthen and St. John. The invertebrate fauna has a Kinderhook facies, though some of the species are allied to Burlington and Keokuk forms. The vertebrate fauna, though in some respects resembling the Chester, is more nearly related to that of a lower horizon, probably Kinderhook. The fossils from the Shenango sandstone are unlike those from the Shenango shales, which are Chester.

In the Sharpsville sandstones is the lower Meadville limestone, which has been recognized in Crawford, Mercer, Warren, and Venango counties by Doctor White, and in McKean and Elk by Mr Ashburner; farther east is the impure limestone of Tioga and Lycoming counties, while on the eastern outcrop, at much the same horizon, allowance being made for thickening in that direction, are the somewhat calcareous, fossiliferous shales described by Doctor White in the report on Huntingdon county. This limestone, hard and flinty at the northwest, is almost non-fossiliferous in Crawford county, but is rich in fossils within Warren and Venango, where the most characteristic fossil is a *Spirifer* very near to *Sp. disjunctus.* Devonian forms occur in the lower divisions, and the Oil Lake group rests on the Riceville shales, which are rich in typical Chemung forms and extend downward to the first Venango oil-sand, the Allegrippus of White in eastern Pennsylvania, the upper Chemung conglomerate of Stevenson.

Closely following this work by Doctor White came that by Professor C. L. Herrick upon the Waverly of central Ohio, which was developed gradually in several publications and took final form in the discussion published in volume vii of the Ohio Reports.

Professor Herrick's investigation was one of the most painstaking ever performed in our country. The "Waverly problem," as it was termed

by Professor H. S. Williams, had been a torment for many years and the conclusions of observers were mutually contradictory. The first result of Professor Herrick's study was the discovery that most of the trouble had arisen from faulty methods of collecting, whereby differentiation of horizons was ignored and fossils from all parts of the series were labeled Waverly.

Underlying the Berea grit of Ohio is the Bedford shale, whose fossils are closely related to those of the New York Hamilton. The Berea grit, evidently the same with the upper part of White's Oil Lake group, is exceedingly poor in fossils, but overlying it is the Berea shale containing characteristic forms, among which are two which occur in the Bedford. This shale is paleontologically similar to the Orangeville of White. On the Berea shale rests the mass known in Ohio as the Cuyahoga and represented in Pennsylvania by the Sharpsville sandstones and possibly by the lower portion of the Meadville. The Sharpsville sandstones are persistent in Ohio as the Buena Vista sandstone, but the great overlying mass of the Cuyahoga seems to have almost disappeared eastward at the Pennsylvania line in the north. The Cuyahoga in Ohio was thought formerly to be very poor in fossils, but Professor Herrick found an abundant fauna at various horizons. The lower portion in northern Ohio contains a fauna which is related to that of the Berea, while the upper portion for 90 to 100 feet below the Logan conglomerate contains a very different and characteristic fauna. The lower shales disappear southward and the true Cuyahoga fauna is found at a few feet above the Buena Vista flags near the Ohio river. The forms characterizing this horizon were collected by Professor Herrick at many localities from the Cuyahoga valley near lake Erie southward to the Ohio river. In the discussion of this fauna he says that "the fossils which have been referred to Carboniferous species seem in every case to have been incorrectly identified," and he concludes with the statement that "enough has been said to show that the Cuyahoga shales are Devonian and lie above the Hamilton." The fauna is Chemung, but not specifically the same as that of New York.

In central Ohio there underlies the Logan sandstone a shale which Herrick named "The Waverly shale."* Here he obtained the fauna described in earlier days as "Waverly," and he shows its unmistakable resemblance to Kinderhook. This fauna passes upward into the Logan conglomerate, which becomes shaly southward, though still retaining the fauna. The Burlington and Keokuk are found in the upper portion of the Logan, from which Professor Herrick made collections at several

* C. L. Herrick: Bull. Geol. Soc. Am., vol. ii, 1891, p. 37.

localities in central Ohio and on the Ohio river, in the southern portion of the state; 250 feet of shales and flags belonging to the Logan remain near Portsmouth, on the Ohio. The lower portion yields a Burlington fauna, while the Keokuk is found in a variable band of red sandstone at the top.*

Paleontological details for Kentucky are wanting, but the Upper Knobstone or Logan is recognizable almost all the way across the state, the underlying Devonian becoming thinner, until in northern Tennessee it seems to disappear. Safford's lists † show that in Tennessee the fossils of the Protean group are Keokuk, though two forms of Burlington affinity are mentioned. In view of the southward disappearance of Kinderhook in Ohio, there is no room for surprise when one finds the Burlington practically missing in Tennessee, and he is quite prepared for the reference of the Alabama Lauderdale to the Keokuk by both Professor Smith ‡ and Mr McCalley.§

It is possible to make an approximate correlation for the several parts of the Appalachian basin, as follows:

Lower Carboniferous:

Shenango and Upper Meadville	Northwestern Pennsylvania	Keokuk, Burlington, and Kinderhook.
Logan, including Waverly shales	Ohio	
Upper 400 feet of Bedford and Huntingdon	Eastern Pennsylvania	
Coal-bearing shales and sandstone	Virginia	
Upper plate of Big Injun	West Virginia	
Upper Knobstone of	Kentucky	Keokuk and Burlington.
Protean of Safford	Tennessee	Keokuk.
Lauderdale of McCalley	Alabama	
Lowest Fort Payne of Hayes	Georgia and eastern Alabama	Undetermined.
Lowest Newman of Campbell	Tennessee and Virginia	

Devonian:

I. Lower Meadville, Sharpsville, Orangeville, and Oil Lake of White	Northwestern Pennsylvania.
Cuyahoga and Berea	Ohio.
Rest of Pocono, Bedford, and Huntington counties	Eastern Pennsylvania.
Lower Pocono of	Virginia.
Upper Grainger of	Southwestern Virginia.

*C. L. Herrick: Ohio Reports, vol. vii, pp. 495–515.

† J. M. Safford: Geology of Tennessee, p. 342.

‡ E. A. Smith: Geological map of Alabama. Exp. chart, 1894.

§ Henry McCalley: Geol. Survey of Alabama, Valley regions of Alabama, part i, 1896, p. 35.

Squaw sandstone, etcetera...........West Virginia.
Lower Knobstone...................Kentucky.
Absent in most of....... ....Tennessee and Alabama.

II. Catskill (of Vanuxem)........ .....Eastern Pennsylvania.
Hampshire of Darton................Virginia.
Absent in Western Pennsylvania, Ohio, Kentucky, most of West Virginia, Tennessee, and Alabama.

III. Chemung and Chemung-Catskill of I. C. White, Chemung of Stevenson, Jennings of Darton.......... } Eastern Pennsylvania, Maryland, and Virginia.
Riceville and Venango of I. C. White. Northwestern Pennsylvania.
Erie shale of Newberry............Ohio.
Absent.............................Tennessee and Alabama.
Grainger shale of M. R. Campbell..Southwestern Virginia and Northern Tennessee.

The correlation is not exact; the details available thus far enable one to make but approximation. Of the names applicable to the upper part of the Pocono, perhaps Logan is the best, as it is the most comprehensive and is the oldest, having been used by Professor Andrews in 1870.* No one of the terms used for the upper division of the Devonian can be taken as a name for the whole, as each one of them has been applied to a definite portion. The limits of the Catskill were set definitively by Vanuxem, but the name had been used earlier by Mather to cover rocks extending from the upper Silurian to the top of the Devonian; it has been used since to designate a condition, and wherever red rocks have been found in the upper Devonian they have been regarded, for this reason, as Catskill. The name has led to serious confusion stratigraphically as well as paleontologically, so that the fishes *Holoptychius* and *Bothriolepis* and the plant *Archeopteris jacksoni* have been spoken of as Catskill fossils, whereas they belong far down in the true Chemung. Mr N. H. Darton's term Hampshire will have to be employed instead of Catskill. There is less objection to retention of the name Chemung, yet it has been used with indefiniteness. Perhaps the slate may be as well rubbed off to begin anew with the name Jennings, offered by Mr Darton and already accepted by the United States and Maryland surveys.

The chief defect of the correlation is in respect to the Catskill or Hampshire; yet correction is extremely difficult, at present impossible. The lowest member of Doctor I. C. White's Oil Lake group in northwest Pennsylvania is the Cussewago sandstone, a flat pebble conglomerate resting on his Riceville shales, which are Chemung. This conglomerate

* E. B. Andrews: Report of Progress, Ohio Geol. Survey, 1870, p. 62.

is present in southern Pennsylvania and northern West Virginia; it is recognizable at more than one locality along the northern outcrop, while along the eastern outcrop a conglomerate often occurs at about the same horizon. At the east this is above the Catskill; in western Pennsylvania it rests on the Chemung.

The Catskill of Vanuxem, consisting of blood-red shales and green to red sandstones, was deposited in a narrow trough very deep at the east and shallowing rapidly westward. In southern Pennsylvania the thickness is 3,700 feet in Fulton county; 1,980 feet in western Bedford, 35 miles away; 10 feet in western Somerset, 35 miles farther west, and nothing in eastern Fayette, 5 miles farther, where the bottom conglomerate of the Pocono (White's Cussewago) rests directly on the equivalent of the Riceville shales. Nowhere in western Pennsylvania is there any deposit answering to the enormous mass of Catskill found on the Alleghanies and eastward. The lowest portion of Dr White's Crawford County Pocono is evidently equivalent to some portion of the transition beds of eastern Pennsylvania. Whether or not any portion of this should be included in the Catskill can not be determined now.

The conditions to which the red beds were due began in New York, within the Catskill region, toward the close of the Hamilton. During the Chemung the influence of these conditions extended westwardly, and especially southwestwardly, spreading red rocks over constantly increasing area, until rocks of that type covered the whole region of the eastern outcrops in Pennsylvania, Maryland, and Virginia to beyond the New river. The conditions were fatal to most forms of animal life, so that we find the fauna surviving for a longer period the farther it was away from the Catskill Mountain area. Occasionally, when the conditions were interrupted, the fauna found its way, at one horizon at least, into the Catskill region itself, near which Professor Prosser found it in the Delaware flags.

In New York the typical Chemung fauna was cut off by the Catskill conditions, while farther west it disappeared with the narrowing of the trough of sedimentation following the deposit of the Riceville and Erie shales. Whether or not there was any sedimentation in Ohio during the Catskill is very uncertain, but the fauna survived somewhere in the northwest portion of the basin and underwent changes during that long period; so that when the Cuyahoga sedimentation occurred in Ohio and northwest Pennsylvania the fauna spread eastward, no longer specifically identical with the old Chemung fauna, but related to it and retaining the Devonian facies.

With the next great change in topographical conditions, that introducing the Mississippian, this fauna disappeared and another took its

place. The discussion of this matter, however, must be deferred until the Mauch Chunk has been described.

The Mauch Chunk of Lesley; Umbral of Rogers

DISTRIBUTION AND CHARACTERISTICS OF THE ROCKS

Range of the Mauch Chunk.—The Mauch Chunk embraces the rocks from the top of the Logan to the base of the Pottsville.

The anthracite strip.—Within the anthracite strip this series consists almost wholly of sandstones and red shale, with here and there thin calcareous beds which become more conspicuous toward the south. It is preserved around the anthracite fields of Pennsylvania, around the Broad Top bituminous area, in a petty area eastward within Fulton county, and at the northern end of the Mount Savage synclinal, which extends southward into Maryland and the Virginias, where the exposure becomes much more important. As the strike sweeps round toward the west in the anthracite fields, the southern field is the nearest to the old shoreline.

Mr Winslow's section near Mauch Chunk, at the easterly end of the southern field, shows a thickness of 2,168 feet, the upper 1,662 feet being red shale and sandstone, the lower portion almost wholly shale;* but at a little way farther north he finds 3,342 feet † almost wholly of red shale. I. C. White measured nearly 2,000 feet in the Catawissa valley, but in the southwest portion of the northern field near Shickshinny the thickness has diminished to only 1,200 feet. Eight miles farther eastward he found only 425 feet, the uppermost 100 being greenish sandstone, the rest red and green sandy shale. Thence northward in this basin the red shales disappear and the mass grows thinner, so that at Scranton the thickness is but 75 feet.‡ Clearly in this region the Mauch Chunk did not extend into New York. H. D. Rogers, in summing up the character of the Umbral as it is shown around the anthracite fields, says that the more argillaceous portions of the red shale frequently contain some calcareous matter, bands of such matter being found occasionally in the upper portion, but becoming more numerous in the middle and lower portions. This calcareous matter is not in beds, but in nodules scattered through the shale. Twelve such beds were observed near Tamaqua, in the southern field, one of them 6 and another 3 feet thick, in which the nodules are very abundant. This description refers especially to the southern and middle fields. In the northern field the calcareous matter

* J. P. Lesley: A summary description of the geology of Pennsylvania (final report), 1895, p. 1815.

† Final report, p. 1635.

‡ I. C. White: Geology of the Susquehanna region (G 7), 1883, pp. 44–46.

occurs chiefly in the sandstones and becomes more abundant* northeastwardly. P. J. P. Lesley calls attention to the presence of calcareous layers near Ashley, in the upper third of the section.† There is practically no information respecting the western extension of the southern field beyond Professor Claypole's statement that the thickness of shale spared from erosion is at least 1,500 feet in Perry county, and that some of the beds contain enough of calcareous matter to make well water hard.‡

The Broad Top coal field may be regarded as in a line with the Northern Anthracite field and the area in Fulton county as corresponding to the Middle field. Only the lower portion of the Mauch Chunk remains in the Fulton area, but the surface is littered with fragments of limestone, always sandy, sometimes red, often bluish. This is the most eastern locality in Pennsylvania at which any of the limestones of the Mauch Chunk are well defined.§ The conditions around the Broad Top field have been studied by I. C. White, Ashburner, and Stevenson. Ashburner's section on the eastern side within Huntingdon county showed a thickness of 1,100 feet, thus:

	Feet
Sandstone and shale	910
Limestone	49
Shale and sandstone	141

The writer was inclined formerly to regard the lowest member as belonging to the Pocono (Logan), but in view of the conditions along the northern border, he now regards it as equivalent to the shale underlying the limestone mass in the oil wells of western Pennsylvania. The limestone is sandy and much of it red. Mr Ashburner discovered a fossiliferous bed containing *Terebratula romingeri*, *Grammysia*, *Strophodonta*, *Rhynchonella*, while lower down is another from which he obtained a *Centronella*.‖ This grouping of forms is so well nigh impossible in the upper Mississippian that one must place these identifications in the same list with those which led to recognition of middle Devonian fauna in the Lower Barren Coal Measures of western Pennsylvania. Stevenson found the same type of limestone on the eastern side in Fulton county, where, however, the limestone appears to be somewhat thicker. On the western side, in Huntingdon county, I. C. White reports 1,050 feet, with the limestone 50 feet broken into alternate bands of limestone and shale and practically non-fossiliferous. In addition to this mass, he discovered

* H. D. Rogers: Geology of Pennsylvania, 1858, vol. ii, p. 10.

† J. P. Lesley: Final report, p. 1823.

‡ E. W. Claypole: Prelim. report on paleontology of Perry county (F 2), 1885, p. 79.

§ J. J. Stevenson: Geology of Bedford and Fulton counties (T 2), 1882, p. 68.

‖ C. A. Ashburner: Aughwick valley and east Broad Top district, in vol. F, 1878, pp. 194–195.

two beds of impure limestone, 2 and 3 feet thick, at 175 and 500 feet respectively below the Pottsville, in which he sees the representative of the upper limestone, which becomes so important beyond the Allegheny mountains.* These upper limestones were not seen in Bedford county by Stevenson, but the lower limestone is persistent there and is present at the northern end of the Mount Savage synclinal, where it shows distinctly the curious current bedding which characterizes it at all exposures farther west.†

Little information is available for localities along the easterly front of the Allegheny plateau in Pennsylvania. R. H. Sanders's section, in Blair county, gives the thickness as 283 feet and shows no trace of limestone, ‡ a condition difficult of explanation in view of observations on all sides. Edward Miller found near the Old Portage, in the same county, 30 feet of limestone, containing "so large a proportion of silex that it forms good mortar without any admixture of sand," which can be no other than the lower Mauch Chunk limestone, the silicious limestone of southwestern Pennsylvania. § Where the Potomac issues from the Alleghanies in Maryland, one has C. C. O'Harra's section, which shows

	Feet
Mauch Chunk shales	800
Greenbrier limestone	227

a total of 1,107 feet. The Mauch Chunk is mostly red shale, but above the middle is a greenish, soft, flaggy sandstone about 100 feet thick, and at the base a brecciated sandstone 4 feet. The Greenbrier is limestone, with thin shales, 70 feet; shales and sandstones, 113 feet, and a silicious limestone, 38 feet, which rests directly on the Pocono.|| Evidently the section varies notably, for within a short distance Rogers reported from Westernport:

	Feet	Inches
1. Red sandstones and shales	650	
2. Limestone, conglomerate, fossiliferous	4	6
3. Red shale, with a little sandstone	184	11
4. Silicious limestone, oolitic bands	46	7
5. Red shale sandstone, some limestone	15	5
6. Silicious limestone, diagonally bedded weathers like coarse freestone	14	4
7. Limestone	7	
Total	918	9

* I. C. White: Geology of Huntingdon county (T 3), 1885, pp. 75–76.

† J. J. Stevenson, vol. T 2, p. 102.

‡ R. H. Sanders, cited by Franklin Platt: Geology of Blair county (T), 1881, p. 13.

§ Edward Miller: Transactions of the Geological Society of Pennsylvania, 1835, vol. i, p. 254.

|| C. C. O'Harra: Maryland Geological Survey, Allegany county, pp. 110–113.

This recalls Doctor White's Huntingdon County section, as number 2 is very near the place of the lower impure limestone.*

Eastern counties of the Allegheny plateau.—Returning now to the north and following the eastern tier of counties on the Allegheny plateau, embracing at the south the great anticlinals of the Viaduct, Laurel, and Chestnut ridges, one finds a succession which was to be expected in view of Miller's discovery in Blair county.

Mauch Chunk rocks decrease in thickness rapidly along the northern border. Shales and sandstones only are reported from Bradford, Tioga, and Sullivan counties. In the last, Franklin Platt assigns but 25 to 140 feet to the whole series; but this estimate is indefinite, including, as it does, only the red shales and ignoring the greenish sandstones as well as the underlying red shale which contains a limestone. In the Barclay coal field of Bradford county the thickness is about 200 feet, shales and greenish gray sandstones, † while in the Blossburg coal field of Tioga I. C. White finds 245 feet of shales and sandstones. Passing over into Lycoming county, west from Sullivan and south from Tioga, one finds Mr Platt's measurement of 75 feet at McIntyre, but this includes only the red shales, and his line of separation differs from that drawn by Doctor White; so that we may regard the thickness in the two counties as the same, taking the larger estimate as preferable. A. Sherwood asserts that the thickness in Lycoming county varies from 271 to 415 feet. Professor Lesley quotes in detail the observations of Abram Meyer in northern Lycoming, according to which the thickness is variable and the section differs extraordinarily from that obtained by other observers. According to Mr Meyer, the thickness sometimes becomes 353 feet, though usually much less. The succession is

	Feet
Shales	20 to 150
Limestone and shale	50 to 75
Shales	80 to 120

A section very similar to that already found in Bedford and Fulton counties, the limestone being somewhat thicker, while the upper shales have lost much. The middle portion of the limestone is silicious, massive, and non-fossiliferous, the only fossils found occurring just below this in a yellow ferruginous bed crowded with encrinal discs.‡

Clinton county adjoins Lycoming at the west. There, at Lock Haven, Doctor Chance finds below the Pottsville 100 feet of red shale, 15 feet of white and gray sandstone, and 3 feet of mixed limestone and sandstone,

* W. B. Rogers: Annual report Geol. Survey of Virginia, 1839, p. 91.

† Franklin Platt: Report of Progress in Bradford and Tioga (G), 1878, p. 127.

‡ A. Meyer, cited by J. P. Lesley: Final report, p. 1803.

but he places only the upper shales in the Mauch Chunk. The limestone was not observed at any locality north or west from that locality; the shales grow thinner northward, so that in northwest Cameron, and even at some localities within western Clinton, they appear to be absent. Doctor Chance is inclined to doubt whether the shales ever reached the western side of Elk county, west from Cameron. Shale is present in Center county, south from Clinton, at Snowshoe, where it is at least 100 feet thick.* The condition in Potter county, north from Clinton, is not sharply defined, and Ashburner was unwilling to draw the line between Pocono and Mauch Chunk, giving for the whole interval of Mauch Chunk and upper Pocono only 70 feet.† Franklin Platt also hesitated to mark any boundary and contented himself with the remark in many places that the Mauch Chunk is very thin. Clearly the upper shale has disappeared.

Ashburner reports 40 to 50 feet of Mauch Chunk in Cameron county and in the greater part of Elk, but at the western side of the latter county the thickness is but 10 to 15 feet, with no red shale. In Forest county, west from Elk, he finds some red shale in the 70 feet below the Pottsville, but in McKean, north from Elk, he finds the Mauch Chunk 50 feet thick on the Cameron border and decreasing northward until it becomes a dark, often coaly shale, varying from 5 to 10 feet.‡

Returning southwardly and entering Clearfield county from the southwestern side of Clinton, one finds few exposures. Doctor Chance in this county and W. G. Platt in the adjoining county of Jefferson were unable to make any satisfactory measurements. Doctor Chance gives 125 feet as probably the extreme thickness for Clearfield.§ The anticlines, which rise so high farther south, are too gentle here to bring up much of the Mississippian.

Cambria lies south from Clearfield and west from Blair, extending eastward to the crest of the Alleghenies. Mr Platt observed the Mauch Chunk beds on the Allegheny slope, but reached the bottom only where the Conemaugh river cuts the Viaduct axis in the south central part of the county, where he estimated the total thickness at 200 feet. A partial section shows ||

	Feet
Red and olive shales and sandstone..........	96
Silicious limestone, exposed	10

* H. M. Chance: Geology of Clinton county (G 4), 1880, pp. 94–96, 125.

† C. A. Ashburner: Geology of Potter county (G 3), 1880, p. 104.

‡ C. A. Ashburner: Geology of McKean county (R), 1880, pp. 63–64.

§ H. M. Chance: A revision of the bituminous Coal Measures of Clearfield county (H 7), 1884, p. 14.

|| W. G. Platt: Report of progress in Cambria and Somerset district, part i (H 2), 1877, p. 46.

The same conditions prevail in the Conemaugh gap through the Laurel Hill axis, where the whole of the limestone is brought up and seen to be much thicker. In the Conemaugh gap through Chestnut hill, within Westmoreland county, J. J. Stevenson found along the Pennsylvania railroad this succession:

	Feet
1. Shales	82
2. Fossiliferous limestone	6
3. Shales and sandstone	60
4. Calcareous shale	3
5. Interval	37
6. Silicious limestone	40 to 50

The same section is shown on the Indiana side of the river.* In that county limestone is present in Chestnut hill almost midway from the Conemaugh to the Clearfield line. In this region one finds for the first time along the lines thus far followed full exposures of this limestone, as farther north and east the deposit is much thinner. It may be well to introduce here a detailed description of it as given originally by Stevenson:

"The upper portion is a conglomerate sandstone of varying thickness, in which are great numbers of more or less angular fragments of the silicious limestone. This passes down imperceptibly into the silicious limestone proper, which in its turn passes into the Pocono sandstone below. The fragments in the conglomerate portion are so clearly free in most cases from all traces of aqueous action that they may have been stripped off by some abrading agent while the limestone bed was above water level.

"The limestone itself is an exceedingly fine grained rock, with a delicate blue color, and on the fresh surface it shows no lines of bedding. It has a flint like fracture and no definite cleavage. On the long exposed surface the color is dull brown and the rock resembles a loose sandstone. Under such circumstances the structure of the rock is perfectly distinct, and it shows curious cross-bedding.

"At first glance this rock is hardly to be taken for a limestone, and the silica evidently predominates at all localities. At the same time lime is present in considerable quantity, for when the rock is burned it becomes snow white, slakes readily, and forms a mortar without the addition of sand."†

The upper fossiliferous limestone is shown in the Conemaugh gap through Chestnut hill, and its thickness suggests that the beds ought to be found at some distance farther north, but Mr Platt appears to have found no traces of it in Black Lick gap of Indiana county. It was not observed in the gap through Laurel hill. The section recalls that obtained by Doctor White in Broad Top, for here one has the upper shales

*J. J. Stevenson: Report of progress in the Fayette and Westmoreland district, part ii (K 3), 1878, p. 48.

†J. J. Stevenson, vol. i (K 3), p. 52. The statement on page 53 respecting the distribution of this deposit is wholly erroneous.

with the impure limestone and the lower or sandy limestone, but the upper shales are very thin and the lower shales are wanting.

A difficulty is encountered in reference to the upper shales, counted here as part of the Mauch Chunk. The lower member of the Pottsville, as shown in northwestern Pennsylvania, evidently disappears southwardly, so that the Sharon coal group is continuous with the Mauch Chunk shale. Stevenson, in his Pennsylvania reports, included that group in the Mauch Chunk, but afterward,* in the light of I. C. White's studies in the northern counties, transferred it to the Pottsville. The Sharon is certainly present in the Conemaugh gap through Chestnut hill, for an insignificant coal bed was seen there directly under the Pottsville; but the group is so thin that no rearrangement of the section is necessary. Farther south, however, the Sharon becomes thicker and its relations will be discussed in a later chapter.

Southward from the Conemaugh the upper limestone quickly becomes important. W. G. Platt does not appear to have found it on the west flank of the Allegheny mountains, in Somerset county, or under the Viaduct axis, though he found the silicious limestone on the Allegheny near Ashtola; but Stevenson found on the west side of Laurel hill, at 20 miles south from the Conemaugh, 16 feet of limestone, separated by about 50 feet of red shale from the silicious limestone below, and thence south he reports frequent exposures to the Youghiogheny gap through Laurel hill, where the two limestones are present on both sides of the anticline. Along Chestnut hill the upper limestone increases rapidly south from the Conemaugh. The two beds of the Conemaugh gap were seeen in the Loyalhanna gap, both thin, silicious, and fossiliferous. On Jacobs creek, the boundary between Westmoreland and Fayette, the upper limestone is exposed for 40 feet, the top portion for 18 feet very pure and the lower portion very argillaceous and with abundant fossils. The section does not reach down to the silicious limestone.† Both limestones are present in the Youghiogheny gap, where the silicious limestone is about 40 feet thick. Stevenson has given recently a section on the National road in Fayette county, which shows shales, 100 feet, and limestone and shale, 150 feet, the latter having at the base 35 feet of silicious limestone, with 35 feet of shales separating it from the main mass of limestone above. There is a concealed space of 23 feet in the lower part of the upper limestone, and the character of the slope suggests that it is filled with readily yielding material, possibly very calcareous sandstone or very sandy limestone, of which a little is shown just above it.‡ Dr I. C. White's studies carry the

* Notes on the Lower Carboniferous groups, etcetera. Amer. Jour. Sci., vol. xxxiv, p. 37.
† J. J. Stevenson: Report on Fayette and Westmoreland district, part i, 1877 (K 2), p. 262.
‡ Notes on the Mauch Chunk of Pennsylvania. Amer. Geologist, vol. xxix, p. 244.

measurements across Preston county of West Virginia, which adjoins Fayette and Somerset of Pennsylvania, where he measured the Mauch Chunk in Chestnut, Laurel, and Briery mountains, the last being the continuation of the Pennsylvania viaduct. Here the order may be reversed and his measurements may be followed southeastwardly, that comparisons may be made with measurements on the Potomac in Maryland.

The Cheat River gap through Chestnut hill is about 20 miles south from the National Road locality just referred to. There Doctor White found shales and sandstones, 299 feet; limestones, 110 feet; silicious limestone, 30 feet; the upper shales containing 10 feet of impure limestone at 40 feet above the base. The silicious limestone varies greatly, being only 5 feet, with 10 feet of overlying sandstone at a little distance from the measured section. The sandstone contains fragments of the limestone as at many localities in southwestern Pennsylvania. Under the Laurel Hill axis, on the west side, at 30 miles south-southwest from the Youghiogheny gap, the section is

	Feet
Shales and sandstones	220
Limestone	94
Silicious limestone	8

with the 10 feet of impure limestone persistent in the shales; but the silicious limestone is as variable as under Chestnut hill, for on the east side of the fold it is 35 feet thick, and the upper part of the Pocono sandstone is calcareous for 10 or 15 feet. At this last exposure the shales are 295 feet, with a thin coal bed within the top 25 feet, while the upper limestone has become 120 feet, an increase eastwardly.* On the west side of the Briery axis, 15 miles south from the last and about 30 miles west from Westernport, in Maryland, the whole mass is thickened greatly, for there the section is

	Feet
Shales and sandstones	370
Limestone and thin shales	227
Silicious limestone	105
Shale	10

No limestone appears here in the upper shales, as the impure limestone of the Cheat river sections has become 20 feet thick, and is included in the limestone mass. The limestone division is less pure than in the Cheat sections, and is broken up into eight beds, aggregating 124 feet 6 inches, separated by beds of red and green shales from 4 to 20 feet thick, so that while there has been an increase in thickness of limestone, that in detrital matter has been still greater. No sandstone occurs in the

*I. C. White: Proc. Amer. Phil. Soc., vol. xx, 1882, pp. 484, 486, 491, 492.

limestone division except near the top. That, however, is the same with that which in the other sections was taken as the bottom of the shales. The silicious limestone is massive except 10 feet at the bottom.* These measurements were made at about 40 miles southwest from the Somerset County exposures under the Viaduct axis.

Western counties of Pennsylvania.—Returning now to the north, one finds in Crawford county of Pennsylvania the Shenango shales of Doctor White, which there vary from 35 to 60 feet and consist of gray to brown and blue shales. The thickness becomes 45 feet near Kinzua in Warren county, east from Crawford, while southward it is 60 feet near Tidioute in Venango and 47 feet near Sharon in Mercer.† Mr Carll gives 50 feet for Warren, northwest from the Allegheny river, but from 120 to 150 feet in the southeastern part of the county.‡ Fossils occur occasionally within Crawford and Erie counties, which, according to White, belong to types characterizing the Chester group. No limestone appears in these shales and they evidently represent the whole sedimentation for the Mississippian in this area.

The relations in the southern counties of western Pennsylvania are shown in the tabulated series of well records given by Mr Carll in his report for 1886. In Crawford county, the Shenango shales are 50 feet; in Venango, 60 feet; in Clarion, east from Venango, 172 feet; in Butler, 90 to 194 feet, increasing southwardly; thus far no limestone. The series is thickening and evidently we have here the upper and the lower shales, between which the limestone should make its appearance. At Pittsburg, about 30 miles west from the Conemaugh gap, through Chestnut hill, the succession differs in some respects from that seen in the gap; the lower shales are here, 44 feet, underlying the silicious limestone, 56 feet, on which rests the upper limestone, which is shaly and 23 feet thick, but the upper shales are absent, so that the Pottsville sandstone is let down directly on the limestone. A similar section is shown at Murraysville, about midway between Pittsburg and the gap, where, however, the upper shale is present, the thicknesses being, shale, 30 feet; limestone, 30 and 90 feet; shale, 60 feet. In Mount Pleasant township of Washington county, about 20 miles southwest from Pittsburg, the lower shale is still present, 27 feet, the upper shale, only 10 feet, while the limestones have diminished to 13 and 29 feet. This, clearly, is not far from the western limit of the limestones, for at the S. B. Phillips well number 1, near McDonald station, 10 miles northwest, no limestone is present and the whole interval from Pottsville to Pocono is but 39 feet.

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*I. C. White: Catalogue of West Virginia University, 1882–'3, p. 50.
†I. C. White: Geology of Erie and Crawford counties (Q 4), 1881, p. 78.
‡J. F. Carll: Geological report on Warren county (I 4), 1883, p. 193.

The record of this well was kept with extreme care and the drillings were tested with acid.* Southward the conditions observed in Chestnut hill prevail, for at Washington, 12 miles south from Mount Pleasant, the lower shales have disappeared, the upper shales are 95 feet, while the limestones are 27 and 58 feet, dark and light respectively. The same condition exists in Greene county, south from Washington, where the upper shale is 55 feet, 20 feet of it being red rock, while the limestones are 55 feet of dark and 110 feet of white, the latter being the silicious.†

This thinning out of the Mauch Chunk across Allegheny and Washington counties is precisely what one should expect in view of the conditions shown by oil-borings within the West Virginia panhandle. Doctor White tells us that in Beaver county of Pennsylvania the thickness is not more than one foot; at Wellsburg, in Brooks county of West Virginia, west from McDonalds, the whole Mauch Chunk consists of but 31 feet of shale and sandstone, while at Wheeling, in Ohio county of the same state, the Pottsville and Pocono are in contact. The western limit of the limestone, passing southwest through Washington county of Pennsylvania, crosses the Ohio river not far below Wheeling, for in Marshall county both shale and limestone occur at Moundsville, the reported succession being:‡

	Feet.
Slate and shells	82
Big limestone	85
Slate	25

Northern and western outcrop in Ohio.—Returning to the north and passing over into Ohio, one finds difficulty in tracing the Shenango shales, for the Pocono becomes shaly in its upper portion and the differentiation between the two divisions has not been carried far beyond the state line. Where the Logan becomes distinctly recognizable in north central Ohio, one finds the conditions as at Wheeling, it and the Pottsville are in contact, so that the Mauch Chunk must be absent; but in the central part of the state, in Muskingum county, the Maxville limestone appears somewhat abruptly. It is the equivalent of the upper or fossiliferous limestone of southwestern Pennsylvania. Professor Orton's general section, given in volume vii of the Ohio reports, marks shale as intervening between the Logan and the Maxville. Professor Andrews, in his description of the Maxville, speaks of 12 feet of clay or soapstone between the limestone and the Logan; but this shale seems to be of very uncertain distribution, for in some localities the limestone

* I. C. White: West Virginia Geol. Survey, vol. i, 1899, p. 227.
† J. F. Carll: Annual report Geol. Survey of Pennsylvania for 1886, pp. 636–660.
‡ I. C. White: West Virginia Geol. Survey, vol. i, pp. 363, 366, 367.

and the Logan sandstone are in contact. The presence of the upper shales is very doubtful, for the coal series begins at 5 to 20 feet above the limestone; so that the upper shales may be regarded as absent, unless indeed some part of the coal-bearing series be taken as their equivalent.

The Maxville limestone was discovered by Professor Andrews in 1869, and was described by him in the Ohio annual report for that year, where he identified it with the Lower Carboniferous limestone of Kentucky. He observed it in western Muskingum and eastern Perry, where it is 17 feet thick, with 4 feet of sandy shale between it and the underlying Logan; it evidently extended across Perry, for it is at least 10 feet thick in Fairfield; in Hocking county, 9 feet were seen at one locality, with the bottom not reached; in Vinton, where it is 16 feet and rests directly on the Logan, it is partly brecciated; 8 feet were seen in Jackson county at 12 feet above the Logan; no exposures were found in Scioto county, but in northeast Greenup county of Kentucky, opposite Scioto of Ohio, he obtained this section:*

	Feet
Coal measures:	
Sandy clay with Coal Measures plants	8
Limestone, pure, fossiliferous	31
Limestone, highly sandy	15
Concealed	10
Waverly sandstone	215

Here the limestone shows its full characteristics, for above is the fossiliferous division and below the silicious limestone, as in Pennsylvania. These are conspicuous farther south. The extent of the Maxville east and northeast from central Ohio is not great, for in southern Noble, the county adjoining Muskingum at the southeast, a record shows it absent at Macksburg, where 21 feet of black shale intervene between the Logan and Pottsville.† Professor Orton states that it is reported in some of the well records in Jefferson, Noble, Monroe, and other counties in eastern Ohio. This is perplexing, for the limestone is absent on the Ohio opposite Steubenville, in Jefferson county, and at Macksburg, in Noble county.

Doctor Newberry states that in northwest Holmes county the Pottsville conglomerate "contains, mingled with its quartz pebbles, rather rudely rounded masses of chert, generally 1 to 3 inches in diameter, which contain Lower Carboniferous fossils." The presence of these fragments, he thinks, shows that the Maxville limestone reached at one time nearly

* E. B. Andrews: Ohio Reports, vol. iii, 1878, pp. 816–822.
† Geol. of West Virginia, vol. ii, p. 299.

to the northern border of the basin, and that it had been broken up and removed by the agencies which transported the materials of the conglomerate.* Mr Read, in his report upon Holmes county, says that the conglomerate contains "large quantities of broken angular fragments of white and yellow chert, with a profusion of fossils identified by Mr Meek as belonging to the Carboniferous formation."† The writer has been unable to find any published statement by Mr Meek in reference to this matter, and the remarks in the reports give no information respecting the horizon to which the fossils belong. In any event, the Maxville limestone in Ohio, as described by Andrews, is not cherty, and no trace of it appears north from Muskingum county, so that it can hardly be the source of the fragments; but the Lower Carboniferous limestone of Michigan, as described by A. Winchell, is cherty, as is also much of the same limestone in Kentucky, so that the presence of these chert fragments points either to Michigan or to Kentucky as the source from which they came. It suggests also an elevation of the land prior to the deposit of the Pottsville, whereby the Lower Carboniferous was exposed to subaerial erosion.

Eastern outcrop in Virginia and West Virginia.—Returning now to the easterly outcrops, we may follow the Mauch Chunk southward to the New river by the aid of the folios published by the United States Geological Survey.

In Pendleton county of West Virginia, at say 30 miles south-southwest from Westernport, Maryland, and at about the same distance southeast from the locality of Doctor White's section, on the Baltimore and Ohio railroad, Mr Darton finds.

	Feet
Shales (Canaan)	1,250
Limestone (Greenbrier)	325 to 400

The Canaan (equivalent to Mauch Chunk of Maryland) shales contain gray and brown sandstones as well as red shale; the limestone is double, the upper division containing much calcareous shale, while the lower division is mostly massive with numerous silicious beds.‡ The deposit retains its characteristics. Messrs Taft and Brooks found on Rich mountain, in Randolph county, of the same state, at say 18 miles west from the last

	Feet
Canaan shales	600 to 700
Greenbrier limestone	350

* J. S. Newberry: Ohio reports, vol. ii, 1874, p. 104.

† M. C. Read: Ohio reports, vol. iii, 1878, p. 545.

‡ N. H. Darton: U. S. Geol. Survey, Franklin folio, 1896.

the shales thickening southward.* The thickness of the limestone is much less than that reported by Stevenson from this region. He found a continuous exposure of 400 feet on the Staunton pike, and at 200 feet lower some calcareous shale; these measurements by barometer and without allowing for the dip. This correction would make the thickness, including the concealed space, upward of 600 feet. The same observer found remarkable variation in the shales. They are wholly absent at a few miles south from the Staunton pike, where a continuous exposure of 30 feet shows the Pottsville in contact with the limestone. Elsewhere they are present, though in at least one locality as thin as 50 feet. A thin coal bed is said to occur on Rich mountain in some shale at about 250 feet below the top of the limestone.† The shales are thicker in the southern portion of the Buchhannon quadrangle than in the northern. Everywhere the lower portion is more sandy than the upper. The lower portion of the limestone is silicious, sometimes containing a conglomerate of quartz pebbles.‡

The Rich Mountain locality is practically on the strike with White's Briery-Viaduct locality, as the Pendleton locality is very nearly on the line with Westernport. The limestone division has increased from 332 feet on the Baltimore and Ohio railroad to at least 600 feet in Randolph, and from 227 feet at Westernport to an average of 350 feet in Pendleton. The thickness of the limestone division in this area should be borne in mind during the study of the apparently perplexing conditions shown by oil-well records within some of the West Virginia counties.

Stamping creek, in Pocahontas county, West Virginia, about 40 miles south from the area of the Buchhannon folio, descends the east slope of Greenbrier mountain. Its line is perhaps 10 miles nearer the old shore than is Rich mountain and not quite so far east as the Pendleton Alleghany. The section on Stamping creek as given by Rogers is

	Feet
Sandstone and shales (Canaan, Mauch Chunk)....	1,260
Limestone (Greenbrier)....	822
Red shale......	50

Unlike those in Randolph county, the upper shales are more sandy above, the sandstones being always fine in grain, red to gray ; the shales, for the most part of " rich brownish red color," are crumbly and contain a little calcareous matter ; the limestones are described as blue and gray, with argillaceous bands, and contain a cherty layer near the top.§

* J. A. Taft and A. H. Brooks : U. S. Geol. Survey, Franklin folio, 1896.
† J. J. Stevenson : Proc. Amer. Phil. Soc., vol. xiv, 1875, p. 389.
‡ J. A. Taft and A. H. Brooks : U. S. Geol. Survey, Buchhannon folio, 1896.
§ W. B. Rogers : Report of progress of Geol. Survey of Virginia for 1839, p. 92.

In 1873 Professor Fontaine made some studies in Greenbrier county, adjoining Pocahontas at the south, where he secured the following measurement:

	Feet
Shale	1,310
Limestone	822

But he gives no details, further than the shales consist of red, green, and brown sandstones and shales. At a later date he obtained at Quinnimont, in Raleigh county, on New river, some characteristic Lower Carboniferous fossils from the upper part of the shales. In Summers county, southwest from Greenbrier, Fontaine estimated the shales at Richmond falls on New river as 1,450 feet, dividing them into

	Feet
Upper, red and variegated	310
Middle, gray shale and sandstone	820
Lower, red shale and sandstone	320

He made no estimate of the limestone further than the statement that it is evidently thicker than at the northern locality in Greenbrier.*

This brings the line to the New river of Virginia. Southward the increasing strength and number of the faults have preserved narrow strips of lower Carboniferous farther and farther east, some remaining even in the Great valley. Before continuing farther along this line, it may be best to turn to the great basin under West Virginia, so that the relations of shales and limestones along the outcrop be not forgotten. For our knowledge respecting this region we are indebted wholly to Dr I. C. White, who has preserved and tabulated a great number of well records.

West Virginia basin.—In crossing Monongalia, Marion, and Wetzel, the northern tier of counties, one notes an abrupt decrease in thickness of the Mauch Chunk. In Monongalia, at barely 20 miles from Cheat River gap through Chestnut hill, the whole interval from Pottsville to Pocono is but 210 feet, filled with "slate, shells, and red rock," 172 feet, and limestone 38 feet. The upper limestone, apparently, is wanting. At Fairview, 15 miles southwest in Marion county, the interval is given as varying from 235 to 255 feet; a detailed section in one well shows shale, mostly red, 195 feet, and limestone 70 feet; but below the latter are sand, red, soft, 5 feet, and sand, limy, yellow, hard, 22 feet, below which comes the Big Injun or Logan. This lower red sand may be the "Keener" of the drillers, which has been regarded in the previous portion of this paper as belonging to the Mauch Chunk. At ten miles farther south-

*W. M. Fontaine; Amer. Jour. Sci., vol. vii, p. 577; ibid, vol. xi, p. 278.

west, near Mannington, in the same county, Doctor White's well shows the interval between Pocono and Pottsville to be 316 feet, thus:

	Feet
Shale, in great part red	191
Blue shale and limestone	28
Red rock	5
Gray limestone	92

The upper limestone is present also at 3 miles north from Mannington, where two limestones are reported at 5 and 22 feet above the silicious limestone, which is 85 feet thick. At Mannington one finds the Fairview condition, for there a white limestone, 17 feet, is found below the thin sandstone, which is marked in the driller's record as the top of the Big Injun. In northwestern Marion the interval is given in one record as 320 feet, with 5 feet of red rock and 68 feet of limestone at the bottom, the upper beds being unrecorded. It may be noted here that in very many wells there occurs, overlying the silicious or lower limestone, several feet of soft rock termed the "Pencil cave."

Great variation appears in Wetzel county, for in the northeast, near the Pennsylvania line, the thickness of Mauch Chunk is 205 feet, which is approximately that of southern Marshall in the "Panhandle," while at 12 miles south it is 257 feet, with 50 feet of silicious limestone at the bottom; but at Smithfield, 4 or 5 miles farther south, it is given as 133 feet, with the silicious limestone 88 feet, while at 2 miles northeast it is said to be 396 feet, with the lower limestone 71 feet, separated by 5 feet of "Pencil" from 20 feet of limestone above. The extreme thinness of Pottsville in this last record suggests that of the unrecorded 200 feet above the limestone much should be referred to the Pottsville. In Marion county, near the Wetzel border, 6 or 7 miles east from Smithfield, everything has disappeared except 50 feet of limestone, which lies between Pottsville sandstone, 105 feet, and Big Injun, 132 feet.

There is great dearth of detail in Tyler, which lies south from Wetzel, there being no complete record of any well in the county. In the northern part, at 20 miles west from Smithfield of Wetzel and 5 miles east from the Ohio river, the interval is given as 255 feet, with the silicious limestone, 68 feet; 5 miles west, on the Ohio river, the limestone is 97 feet, but at 2 miles farther west-southwest it is only 40 feet, while near Hebron, 12 miles farther south, the whole interval is said to be 360 feet, with the limestone 100 feet. No details are available for the little county of Pleasants, adjoining Tyler along the Ohio river, but Doctor White states that the shales disappear.*

*Geol. of West Virginia, i, pp. 236, 240, 243, 245, 343, 345, 348, 349, 356, 357, 360.

The upper division of the limestone is apparently persistent, though irregular as far westward as Wetzel county, while the distribution of the shales is very irregular; the silicious limestone is clearly persistent through the four northern counties to the Ohio river, and in such thickness that it ought to be present in eastern Monroe and northeast Washington of Ohio; but the western limit is not far away in Ohio, for a record in Pleasants county, near Eureka, on the Ohio river, appears to show that the Mauch Chunk is absent, as it gives 375 feet of continuous sandstone for Pottsville and Pocono, with no limestone for more than 300 feet above or below, and this is confirmed by the record of another well farther down the river.*

The next tier of counties consists of Harrison, Doddridge, Ritchie, and Woods, the last extending along the Ohio river farther west than Pleasants.

Sardis district is in the northwestern corner of Harrison. There, at say 10 miles southwest from Mannington, in Marion county, a well was drilled for Doctor White, and the record was kept with such scrupulous accuracy as to give a standard not only for this tier of counties, but also for that next at the south, where a record is available much farther east. The writer, in view of the conditions along the outcrops, ventures to draw the boundary between Mauch Chunk and Pocono at a somewhat lower horizon than has been done by Doctor White; but this is rather a matter of detail, as affording a more convenient mode for the comparisons to be made in later portions of this paper. The section below the Pottsville, as rearranged, is

	Feet
1. Slate and shells	8
2. Limestone and slate	10
3. Limestone, hard	30
4. Red rock	15
5. Black slate	37
6. Limestone, hard, blue	6
7. Limestone and shells	12
8. Red rock	5
9. Black shale ("Cave"?)	11
12. Limestone	49
13. Sandstone, gray	7
14. Limestone, gray	32
15. Black shale	4
16. Limestone, gray	14

below which comes sandstone, 45 feet, to bottom of the well. This last may be taken as the Logan, so that the interval is 240 feet. Reference

*I. C. White: Op. cit., p. 353.

to the Marion County records shows a notable change in the upper part of the section, for the shales and sandstones have disappeared, while the upper limestones of the Mannington well have increased greatly. The general structure of the silicious limestone, numbers 12 to 16, is that observed at both Fairview and Mannington. The thickness varies, being 97 at Fairview, 146 at Mannington, and 106 at Sardis, but the extreme thickness at Mannington is due mostly to the local increase of the sandstone, number 13, which there is 37 feet. A record in the southern part of the county shows the sandstone still present, with 96 feet of limestone below it.

Near Center Point, in Doddridge county, about 10 or 12 miles west from the White well, the section is similar, though differing somewhat in detail. It is given in full:

	Feet
1. Slate	9
2. Limestone	40
3. Red rock	36
4. Limestone	13
5. Red rock	11
6. Slate	9
7. Limestone	31
8. Slate ("Pencil")	15
9. Limestone	58
10. Sandstone	13
11. Shale	2

resting on 72 feet of sandstone to bottom of well. Here, as at Sardis, the upper shales are probably wanting, for the Pottsville rests on number 1. The limestone of the upper division has increased, as has also the upper part of the silicious limestone. The "Keener" persists, but the lower part of the limestone seems to have disappeared. Another well near by shows no shale, but a great increase in the upper limestones, which are, descending, 56, 39, 30, while the silicious has become 69 feet. Ten miles south from this locality the Mauch Chunk interval is given as 310 feet, with slate shells and limestone 230 feet; slate, 10 feet; limestone, 77 feet. This appears to show that the upper shales are present. A notable change in conditions appears in south central Doddridge, where at 8 miles east from the Ritchie county line the whole interval is but 105 feet, not including the "Keener," and the silicious is but 25 feet. The rocks above the latter are unrecorded.

Passing over into Ritchie county, one finds the records abundant and interesting. In southeastern Ritchie, about 8 miles from the last-mentioned locality in Doddridge, a record gives limestone, 18 feet; "Dark lime, shale, and hard shell," 82 feet—practically the same interval as the

last; the shales are absent and the limestones cannot be differentiated. Four miles west the record gives 69 feet of limestone, but says nothing of the overlying rocks. In northern Ritchie, at about 15 miles north from the last and about 10 miles west from the Doddridge line, the interval varies within a few feet from 20 to 75 feet, the limestone being 20 and 67 feet. There can be no doubt respecting these records, as they are given on the authority of Mr J. F. Carll. It is sufficiently clear that in this portion of Ritchie only the silicious limestone remains. At Harrisville, in the center of the county, shale, 8 feet, and limestone, 91 feet, are reported, while at Cairo one finds in the 90 foot interval 16 feet of "Pencil" resting on the limestone, which at 50 feet from the top shows a 12-foot sandstone; but the shale is absent from a well near by. Four miles northeast from Cairo no shale is present and a 10-foot sandstone is at 5 feet from the top of the limestone; but 8 miles south from Cairo the interval is 67 feet, filled with limestone. Doctor White states that the upper shales are wanting throughout Ritchie, Tyler, Pleasants, Wirt, Wood, and counties along the Ohio. In western Ritchie the interval is from 16 to 44 feet and is filled with limestone. In the Hendershot field, within central Wood county, the thickness of Mauch Chunk varies from 0 to 90 feet, the last being in the southerly part and 5 miles from the other. Near the last the record gives the interval as 48 feet, with limestones 15 and 18 feet, separated by 15 feet of shale; but at Parkersburg, on the Ohio, at 5 miles southwest, the limestone has disappeared, and between the Logan and the Pottsville one finds 65 feet of less massive rocks, which may belong to either one or the other. The limestone is absent from central and southern Washington county of Ohio, adjoining Pleasants and Wood of West Virginia.*

The western limit of the silicious limestone is along the Ohio river from north Washington county of Ohio to a little below Waverly in Wood county. It passes east from Parkersburg.

The next tier of counties consists of Lewis and Braxton at the east, then Gilmer, Calhoun, Wirt and Roane adjoining Calhoun, Jackson, and Mason along the Ohio river.

Lewis adjoins Harrison at the south. Here one finds a record of great value for the proper interpretation of the Harrison County records, for the boring was made at the extreme eastern border of the county and barely 25 miles from the exposures in Rich mountain of Randolph county. The succession is

*The references for this tier of counties are Geol. of West Virginia, vol. i, pp. 250, 253, 285, 287, 294, 296, 297, 300, 301, 303, 306, 309, 314, 315, 318, 320, 322, 325, 329, 330.

		Feet.
1.	Shales	100
2.	Sandstone	65
3.	Limestone	95
4.	Sandstone	5
5.	Limestone, white	30
6.	Sandstone	10
7.	Red rock ("Pencil")	5
8.	Limestone	55
9.	Sandstone	10
10.	Limestone	20
11.	Shale	50

resting on the Pocono sandstone, 215 feet. We have here the upper shales, 165 feet; the upper limestone, 140 feet; the "Pencil," 5 feet; the silicious limestone, 85 feet, and the lower shale, 50 feet; in all, the limestone is 230 feet. Comparing this with the measurements on Rich mountain by Taft and Brooks, one observes a decrease in the shales from 600 to 165 feet, which is what might be expected, since Mr Darton gives 1,250 feet for the shales farther east in Pendleton county. The limestone has decreased, though not to the same extent, there being, according to Messrs Taft and Brooks, 350 feet in Rich mountain. If Stevenson's figures for Rich mountain be accepted, the decrease in the limestone would be comparable with that in the shale. From what has been learned of conditions in the western counties, it is probable that the decrease is mainly in the upper limestone, for thus far the silicious limestone tends to hold its own. At this locality one is on the east side of the Chestnut Hill anticlinal, which has become so gentle that it is crossed by the Pittsburg coal bed. The section may be compared with that obtained by Doctor White under this axis on Cheat river. There the shales are 299 feet and the limestone 140 feet, including the silicious limestone; the shale has decreased, while the limestone has increased.

With this Lewis record may be compared that of a well drilled near Sutton, in Braxton county, about 35 miles southwest of the last and about an equal distance northwest from the Stamping Creek locality in Pocahontas county. It is very nearly on the strike with the well in Lewis county. The succession is

		Feet
1.	Slate	30
2.	Limestone	35
3.	Red rock	15
4.	Black shale	10
5.	Limestone	50
6.	Slate	20
7.	Sand	15
8.	Limestone	290

resting on a great mass of shales, the Logan having lost its massive character and assumed the shaly phase characterizing it farther south. No differentiation of the limestone is given in the record, so that one can not recognize the silicious portion; but the great increase is in the lower portion, for in Braxton, as in Lewis, the sandstone is at 130 feet below the top, while above the sandstone there is decrease of calcareous matter. The most notable feature as compared with Stamping creek is the decrease in the shales, which here are barely one-fortieth of what they are at the easterly locality and one-fifth of what they are in Lewis. The thickness of limestone is more than one-half that on Stamping creek and nearly double that in eastern Lewis, showing that while the thickness diminishes in general direction of dip, it increases southwardly along the strike.

No other record is available for Lewis until Vadis is reached, on the western border of the county, about 20 miles west from the eastern line, 30 miles due north from Sutton, and 20 miles south-southwest from the well in southern Harrison county. The succession at Vadis is

	Feet
1. Shale	10
2. Limestone	20
3. Slate	30
4. Limestone	30
5. Slate	75
6. Sand	15
7. Limestone	30
8. Red rock ("Pencil")	2
9. Limestone	18
10. Sandstone	15
11. Red rock	5
12. Limestone	35

resting on the Logan sandstone, 195 feet. There is an increase in the upper limestone division, but it is due to detrital matter, for in crossing the county the limestone above the "Pencil" has decreased from 125 to 80 feet, and the upper bed of 95 feet has become two, respectively 20 and 30 feet. The decrease of the shales continues westwardly, and shows the approach of the conditions observed in Doddridge immediately west from Vadis, where within a short distance the shales, as well as most of the upper limestone and its shale, has disappeared. The change becomes more notable in the record of a well near Glenville, in Gilmer county, 10 miles west of south from Vadis and nearly on the strike with it. The record is

	Feet
1. Blue shale	25
2. Red rock	30
3. Blue shale and lime shells	15
4. Red rock	20
5. Limestone and sand shells	39
6. Black limestone	23
7. "Pencil"	6
8. Limestone, silicious, blue	57

but below the last the rock is described as "broken and limy," so that the full thickness of the silicious limestone is not given in the record. An unexpected feature is the practical disappearance of the topmost limestone of eastern Lewis, 95 feet thick, which is represented at Vadis by 50 feet of limestone and 30 feet of shale. The red rock has increased greatly, and of the upper limestones there remains only the lowest bed. Meanwhile there has been a decrease in thickness of the section and the sandstones are represented only by fine material; the Logan, as a sandstone, has disappeared, and the driller found nothing worthy of record for 639 feet below the limestone.

Doctor White gives no record for wells in Calhoun county, that adjoining Gilmer at the west, but a record at Burning Springs, in Wirt county, 28 miles northwest from Glenville, shows under the Pottsville 115 feet of limestone, "very hard, and lower half mixed with sand." Burning Springs is but 10 miles south from the locality in southern Ritchie, where 67 feet of limestone represents the whole series. Spencer, in Roane county, is 30 miles south of west from Glenville and barely 15 miles south from Burning Springs. There the limestone is 75 feet, the lower 45 feet being "gritty;" 20 feet of shale and sandstone intervene between it and the Pottsville sandstone above, and it rests on the blue shales of the Logan. In another well, 11 miles southwest from Spencer, the limestone is 86 feet, the lower portion for 25 feet being "gritty, very white," while the upper part is gray. This well is about 40 miles west from that at Sutton; within this distance the limestone has decreased 360 feet.

Jackson county lies west from Wirt and Roane. The record is at Ravenswood, on the Ohio river, 25 miles from Spencer, 30 from Burning Springs, and 25 south of west from Parkersburg, in Wood county. The succession is

	Feet
1. Shale	42
2. Limestone and sand	38
3. Black shale	12
4. Limestone	68
5. Limestone and sand	50

resting on the mass of Logan shale. The 118 feet at the bottom may be taken to represent the silicious limestone; the black shale, the "Pencil" of wells farther east. In that case number 2 would represent the upper limestone and number 1 would be either the upper shales or continuous with the upper portion of the limestone. That these are the proper assignments appears very probable from the record of a well 25 miles southwest from Ravenswood, in Mason county, opposite Gallipolis, Ohio; for there the driller reports shale 45 feet, limestone 165 feet, separated from the hard Logan below by 10 feet of shale. The limestone is not differentiated in the record. Gallipolis is less than 30 miles east from Maxville exposures in Ohio. At Letart, in northern Mason, on the Ohio, and 12 miles west from Ravenswood, the condition is sufficiently clear, for there one finds

	Feet
1. Limestone	60
2. Hard sand and gray shale	4
3. Limestone	10
4. Gray sand and limestone	24

Number 1 is the Maxville limestone as exposed in central Ohio, and numbers 3 and 4 are the silicious limestone, which is becoming thinner in this direction, to disappear before the Maxville outcrop has been reached. It will be remembered that Andrews discovered this portion of the limestone in Kentucky.*

Kanawha county lies south from Roane. At the Burning spring, 40 miles south from Spencer, blue limestone, 300 feet thick, underlies the Pottsville and rests on shales of apparently great thickness. The lower portion of the limestone is more or less silicious, but the driller did not differentiate the portions, so that their respective thicknesses can not be given. This locality is about 50 miles south-southwest from Sutton, in Braxton county, and probably 10 miles westward off the line of strike from that place. The limestone is considerably less than at Sutton, but detrital beds appear to form a very small part of the mass. At Central City, in Cabell county, 50 miles west from the Burning spring and 30 miles south from Gallipolis, the limestone is 150 feet, with 28 feet of shale between it and the Logan below. Andrews's section, in Greenup county, Kentucky, is less than 30 miles west from Central City.

Lincoln county is southeast from Cabell and southwest from Kanawha. In its southern portion, on the border of Mingo county, a record gives 235 feet of limestone divided at 75 feet from the bottom by 2 feet of sandstone. This is 35 miles south-southwest from the Burning spring

*The references for this tier of counties are Geol. of West Virginia, vol. i, pp. 255, 258, 260, 262, 264, 268, 270, 274, 282, 284.

and about 10 miles off the strike westward. Mingo county, adjoining Lincoln at the south, extends to the Kentucky line at the Big Sandy river. Near Dingess, 10 miles west-southwest from the last locality, a record gives

	Feet
1. Black shale	22
2. Gray limestone	6
3. Red rock	4
4. Gray limestone	2
5. White shale	4
6. Red rock	2
7. White shale	34
8. Gray shelly limestone	51
9. White hard limestone	125

resting on the Logan sandstone. The shaly upper portion, 72 feet, is about the same as in Lincoln county, but contains limestones. The shales thicken westwardly, for, at 10 miles away on the Big Sandy, opposite Warfield, Kentucky, they are 153 feet, with 4 feet of limestone separating them from 60 feet of shale and sandstone, while at a little farther south they are 195 feet, resting directly on 40 feet of sand, with no intervening limestone. The main limestone thickens southwardly, being 205 feet at the last locality, where the whole thickness is 440 feet. It is easy to recognize in this Mingo County section the Chester and Saint Louis limestones of the Kentucky geologists.*

Along the eastern and southern outcrops.—Returning now to the outcrops at the east, south from the New river and eastward into the Great valley, information is wanting respecting the counties of Highland, Bath, and Alleghany, Virginia, which are east from Pocohontas and Greenbrier of West Virginia, as well as respecting Monroe of West Virginia, south from the New river. The numerous faults beyond the Alleghany mountains of Virginia, beginning near the Greenbrier river, have led to the preservation of narrow strips of Mississippian farther toward the Great Valley than at the north, so that in Montgomery, Pulaski, Wythe, and Smyth counties small areas remain even in the valley itself.

In the petty areas of Mississippian within the Great Valley, already referred to in the previous pages on the Pocono, the Mauch Chunk is represented almost wholly by shale. No measurements are known for the Catawba Mountain area, but in the Price mountain of Montgomery Professor Fontaine measured 1,090 feet of shale, which he regards as in part contemporaneous with the Greenbrier limestone.* The shales are present in the little area along the Norfolk and Western railroad west

*The references for these counties are Geol. of West Virginia, pp. 272, 275, 277, 278, 279, 280.

*W. M. Fontaine: Amer. Jour. Sci., vol. xiii, p. 119.

from Pulaski, but they have suffered so severely from erosion that the writer made no effort to estimate their thickness. The silicious limestone is there, but very thin, less than five feet.

The Brush-Cloyd-Little Walker Mountain strip, forming the northerly boundary of Montgomery, Pulaski, and Wythe counties and extending a little way over into Smyth county, shows no limestone in Montgomery, according to Fontaine and Stevenson. The latter found no limestone in Pulaski county, and only the silicious limestone 7 or 8 feet thick in western Wythe. The thickness of the shales in New River gap, through Little Walker mountain, was estimated at 996 feet, the boundary between Mauch Chunk and Pocono being drawn arbitrarily, there being no limestone present; but the limit as given accords with the place of the silicious limestone in Wythe and Bland. The silicious limestone, still very thin, was seen in southern Bland county, north from Wythe, along the foot of Brushy mountain, where also a streak of coal occurs in the overlying shales. The shoreward boundary of the silicious limestone extended along the strike within the valley little farther than the eastern border of Wythe county. It may have reached as far as the line of the Blue Ridge, for the fragment on the Norfolk and Western railroad is within 12 miles of the pre-Cambrian rocks. The limestone mass, so thick at only a few miles west and northwest, appears to be represented in Wythe and Bland only by a few feet of the silicious limestone and to be wholly wanting in Pulaski and Montgomery.*

The fault of Walker mountain diminishes westwardly, so that its Mississippian area is cut off suddenly at a little way beyond the Smyth County line; but the great Saltville fault increases in that direction, and its Brushy Mountain exposures continue through Smyth and Washington counties into Tennessee. Along this line the limestone increases in thickness, so that in central Smyth county it becomes a notable feature, attaining its greatest thickness in Washington where the Holston river breaks through Brushy mountain. There Stevenson estimated the shales at 1.000 feet, the upper limestone at 1,270 feet, and the lower at 755 feet. These were merely estimates made during a preliminary reconnaissance, and they are doubtless excessive. The shales consist of red shales, fine grained sandstones, and grits, with some thin limestones, the

*J. J. Stevenson: Proc. Amer. Phil. Soc., vol. xxiv, pp. 75, 76, 100. Mr M. R. Campbell visited this region several years after the publication of results obtained by Fontaine and Stevenson. He came to very different conclusions respecting the relations of the Price Mountain shales, as well as of those along Little Walker mountain. He does not regard them as contemporaneous with the Greenbrier limestone, as he recognizes that limestone in Wythe county, where he finds a thickness of about 1,500 feet, as opposed to the practical absence of limestone asserted by Stevenson. It is impossible to reconcile these figures, and nothing can be done now further than to state the case. For the present, however, the writer prefers to accept his own observations as apparently in accord with conditions in similar petty areas farther south.

whole becoming more or less calcareous in the lower portion. The upper limestone is not wholly exposed, there being a concealed space, estimated at 250 feet, beginning at 105 feet from the top and containing in its upper portion a thick bed of sandstone. Apparently at least one-half of the total thickness is shale, of which one bed, estimated at 150 feet, is almost midway in the section. Many of the limestone layers are very impure. The fossils from beds as far down as to within 80 feet from the bottom are similar to those obtained from the upper limestones in southwest Pennsylvania. The lower limestone is very distinct from the upper. Chert is present in almost every bed. Some shales are present, but limestone predominates throughout. The fossils differ from those in the upper limestone.* Mr Campbell has named the shales Pennington and the whole limestone Newman. Along the same line in Scott county of Virginia and in northern Tennessee the thickness of the Newman limestone is estimated by Mr Campbell as at least 1,500 feet, but he makes no estimate there of the Pennington, as it has suffered much from erosion.†

A space 15 or 20 miles wide intervenes between the Brushy Mountain strip of Mississippian and the next at the northwest, the latter being not very far off the strike with the Alleghany of Pendleton, Alleghany, and Greenbrier counties. No information is available at present for Monroe county of West Virginia, but observations are recorded for Summers and Mercer counties, those lying next to Monroe on the dip. These observations are somewhat at variance.

Professor Fontaine, as already stated, found near Hinton, in Summers county, shales 1,450 feet resting on the limestone. Mr Maury gives 3,500 feet as the aggregate thickness of the whole Mississippian in the neighborhood of Hinton, which, after deducting 1,160 feet for the Pocono, as measured by Fontaine, would give somewhat more than 2,200 feet for the limestone and shales.‡ Messrs Campbell and Mendenhall describe the Hinton formation, the upper portion of the shales, as a "heterogeneous mass of variegated shales and sandstones of varying character and impure limestones, ranging in thickness from 1,050 to 1,100 feet." The lowest bed is a heavy sandstone, which is above the river bed at Hinton. They call especial attention to the conglomerate character of this sandstone, the pebbles consisting of dark slightly sandy shale. They see evidences of local erosion in the finer portions of the sandstone, the eroded portions being filled up with the conglomerate.§ Apparently

* J. J. Stevenson: Proc. Amer. Phil. Soc., vol. xxii, p. 135; the same, vol. xix, p. 258 et seq. The measurement given for the lower limestone in the latter paper should be diminished by 100 feet, as the lowest portion should be referred to the Grainger shales of Campbell, which are Devonian.

† M. R. Campbell: U. S. Geol. Survey, Estillville folio, 1894.

‡ M. F. Maury: Resources of West Virginia, 1876, p. 187.

§ M. R. Campbell and W. C. Mendenhall: Seventeenth Annual Report U. S. Geol. Survey, 1896, pp. 487-489.

the Hinton formation includes the upper and middle portion of Fontaine's Umbral shales.

Beyond New river, in Summers and Mercer counties, Mr Campbell finds the Hinton about 1,200 feet, very largely red shales, resting on the Bluefield, 1,200 feet thick, mostly blue shale and very calcareous at the bottom. The latter must be the equivalent of Fontaine's lower division, and the whole is equivalent to the Pennington shale of Campbell, in Scott county of Virginia. Above the Hinton is a mass of sediment, which Mr Campbell placed at one time in the Mississippian, but in the paper just quoted it is transferred to the Pottsville.* There is substantial agreement respecting the thickness of the Hinton formation, Fontaine making it 1,130 feet on the Chesapeake and Ohio railroad, where Campbell finds 1,050 to 1,100 feet. Stevenson gives for southern Summers 973 feet down to the top of the great sandstone at Hinton, while Campbell gives as the average of the Hinton for Summers and Mercer about 1,200 feet. The especial difficulty is in the extraordinary thickening of the lower portion of the Fontaine section, the Bluefield of Campbell, an increase of 400 per cent within a few miles from New river. The Greenbrier limestone, in northeast Tazewell, adjoining Mercer, is given by Campbell as about 1,200 feet, but it decreases westwardly so as to be only 900 feet in the western portion of that county, where the lower beds are very cherty. Northeast Tazewell is barely 25 miles north from the Little Walker locality, in Wythe, where only the lowest part of the limestone remains.

The weakening of the faults in west-southwest direction soon cuts off the narrow strips observed in Tazewell and Scott counties, and the next exposures are found in Wise and Lee counties of Virginia, the latter on the Tennessee border, along the edge of the Cumberland plateau. It will be remembered that Mr Campbell estimated the thickness of the Newman limestone in Brushy mountain near the Tennessee line at not less than 1,500 feet. This is in Scott county. Barely 25 miles northwest one comes to Big Stone gap, in Wise county, where Mr Campbell finds 829 feet of Newman limestone and 1,025 feet of Pennington shale. The latter is shown at 10 or 15 miles farther northwest, in Hurricane gap, through Pine mountain, in Kentucky, with a thickness of 890 feet.† The Pennington consists of shales, sandstones, and a few thin limestones, one of which, near the middle, is fossiliferous. There is a similar bed at this horizon in the Hinton. The lower third consists almost wholly of sandstone. The limestone section as given by Mr Campbell is separable into an upper division of 451 feet and a lower of 378 feet. The

* M. R. Campbell: U. S. Geol. Survey, Pocahontas folio, 1896; Tazewell folio, 1897.

† Professor Crandall, of the Kentucky Geological Survey, represents the Pottsville as in contact with the limestones in Hurricane gap.

upper contains only 155 feet of limestone in nine beds, all of them impure and many of them apparently approaching calcareous shale. Of the rest, 81 feet are described as calcareous shales or calcareous sandstones. The important sand deposits are at about 90 feet from the top. It is evident that in this direction the mass is not only thinner, but less calcareous than in the Brushy Mountain region. The lower division is described as "heavy blue limestone, becoming cherty toward base."* This must be kept in mind during the study of the Bangor limestone farther south. At Pennington gap, in Lee county, Stevenson estimated the lower part of the Pennington shales at 350 feet and the limestone at 765 feet. The characteristics of the several portions resemble those given by Mr Campbell. Heavy sandstones are at the bottom of the shales, and the lower part of the Newman is a massive limestone. The conditions suggest that the lower part of the New River section has disappeared in the shales, and that there remains here only the Hinton of Campbell, the upper and middle portions of Fontaine's grouping.

Eastern outcrops in Tennessee.—The Brushy Mountain strip of Newman (Greenbrier) limestone extends into Tennessee not more than 15 miles, as the Saltville fault loses strength. The thickness remains about the same as in Virginia, 1,500 feet, but, excepting 100 feet of massive limestone at the bottom, it consists of shales and shaly limestones. Farther westward, in Claiborne county, along the face of the Cumberland plateau, it has 700 feet of solid limestone, strangely in contrast with the condition in Lee and Wise counties of Virginia along the same line.

A petty area like those of Wythe and Montgomery counties of Virginia remains in Blount county on the Chilhowie mountains, not more, according to Safford's map, than 15 miles from the pre-Cambrian rocks. There the thickness of the Newman is about 600 feet, with limestone at the bottom, rich in fossils, but the greater portion above consisting of shales carrying a little limestone. The thickness increases somewhat northwestwardly, so as to become 700 feet, with the lower portion containing much chert. Along the face of the Cumberland plateau the condition observed in Claiborne county continues southwestwardly through Campbell and Anderson, the Newman limestone varying from 600 to 700 feet, mostly limestone, and with few beds of shale. Near Big Spring gap it shows 130 feet of cherty limestone at the bottom, which is not equally conspicuous elsewhere. The Pennington shale, like the Newman limestone, increases southwardly, and varies from 160 to 400 feet; but the whole series decreases westwardly, for in Morgan county

*M. R. Campbell: Geology of Big Stone Gap coal field. Bull. U. S. Geol. Survey, no. 111, 1893, p. 39.

the limestone becomes 400 feet, while in the northern part of that county the Pennington shales disappear. The limestone contains a 10 to 30 foot sandstone at 150 feet from the top.*

The eastern portion of the Cumberland plateau is known as Waldens ridge in Roane, Rhea, and Hamilton counties, the last extending to the Alabama-Georgia line. The Newman limestone of Mr Campbell is divided by Mr Hayes into Bangor limestone above and Fort Payne chert below—a distinction more or less exact for the whole eastern outcrop. Mr Hayes finds the Fort Payne 75 feet thick in Roane, but at a little way farther east it is hardly distinguishable from the overlying limestone. It thickens southwestwardly until it becomes 150 feet in Hamilton; at the bottom it consists almost wholly of heavy beds of chert with little shale or limestone, while higher up it is more calcareous and passes gradually into the limestone above. This is the silicious group of Safford, † and Mr Hayes's description enables us to recognize here both divisions of that group, the Protean or Logan below the more calcareous Lithostrotion above. The Bangor of Hayes, equivalent to the Mountain limestone of Safford and the upper Newman and Pennington of Campbell, attains great thickness along this eastern side of Waldens ridge, being apparently nowhere less than 800 feet, while in Hamilton it is reported as 1,100 feet, which, added to the 150 feet of Fort Payne, makes nearly twice the thickness reported from the Chilhowie mountains. In the White Oak mountains, about 15 miles east from Chattanooga and very near the Georgia line, a condition begins which becomes more noteworthy in Alabama. The upper part of the Fort Payne becomes a calcareous sandstone and is separated from the Bangor limestone by from 600 to 800 feet of mostly black carbonaceous shale, the Floyd shale of Mr Hayes. This he recognizes as contemporaneous with the lower portion of the Bangor farther west, for the limestone is but 600 feet thick. The Floyd shale contains a few streaks of impure limestone. A narrow strip of Mississippian is shown on the west side of Waldens ridge in Cumberland, Bledsoe, Sequatchie, and Marion counties, about 12 miles from the east face of the ridge. It is known as the Sequatchie valley and extends for many miles into Alabama. The Bangor is from 800 to 1,100 feet thick in this valley, and a hard sandstone, 15 to 20 feet thick, is seen at many places about 280 feet from the top ‡

Outcrops in Georgia.—Somewhat isolated areas of the Mississippian remain in northwestern Georgia, west from the Oostanoula and north

* Arthur Keith: U. S. Geol. Survey folios—Morristown, 1896; Knoxville, 1895; Loudon, 1896; Briceville, 1896; Wartburg, 1896.

† J. M. Safford: Geology of Tennessee, pp. 338-339.

‡ W. C. Hayes: U. S. Geol. Survey folios—Kingston, 1892; Chattanooga, 1892; Pikeville, 1895.

from the Coosa river. The White Oak Mountain area of Tennessee, extending into Catoosa county, may be regarded as on the strike with Taylors ridge in Catoosa, Walker, and Chattooga counties, which may be taken as the westerly boundary of the Valley outcrops. The area in Catoosa is insignificant, 1 to 2 miles wide, but southward its width becomes fully 12 miles and the eastern edge is in Whitfield, Gordon, and Floyd, or about as far toward the old land as the Chilhowie area in Blount county of Tennessee. The condition observed in the White Oak mountains within Tennessee becomes more marked. The Fort Payne appears to be about 75 feet thick, very cherty below, and showing coarse, cherty sandstones above, which Mr Hayes thinks were originally more or less calcareous. The Floyd shale, synonymous with the Oxmoor sandstone of the later Alabama reports, is mostly sandstone in the White Oak mountains of Catoosa county, but mostly black carbonaceous shale in Floyd and Chattooga, becoming rather more calcareous westward toward Taylors ridge. A thin-bedded sandstone is in the upper portion. The Floyd is from 1,350 to 850 feet, decreasing northwestwardly. The Bangor is found east from Taylors ridge and 500 feet thick, so that it must have extended at one time eastward into Floyd county. Westward, in Walker and Dade counties, around the northern end of Lookout mountain and along the easterly face of Sand mountain (Waldens ridge of Tennessee), the Floyd shale is wanting, the Fort Payne becomes 200 feet, and the Bangor 750 feet.*

Eastern outcrops in Alabama.—From Georgia there passes into Alabama the narrow strip on the east side of Lookout mountain, the broader strip between Lookout and Sand mountains; from Tennessee, the Sequatchie valley, known in Alabama as Browns valley. The earlier work by Mr Hayes, which gave the structure and set forth the succession, has been superseded by Mr McCalley's detailed work for the Alabama survey, so that the latter must be the guide in tracing the formations through this state.

The extreme southeastern exposures are in an irregular but almost continuous area, crossing Calhoun, Saint Clair, Talladega, and Shelby counties, which may be regarded as lying a little farther eastward than the Floyd-Gordon area of Georgia. Here the Fort Payne diminishes southwardly and southwestwardly, the thickness varying from 275 to 0 feet. It disappears in southern Shelby and southwestern Talladega; along the southeasterly side of the area in Calhoun it is not more than 25 feet; but in Saint Clair it becomes 275 feet, and with increasing thickness shows an increase of calcareous matter. The Bangor limestone is

* W. C. Hayes: Geol. Survey of Alabama, Bull. no. 4, 1892, pp. 44-48; U. S. Geol. Survey, Ringgold folio, 1894.

absent throughout, being represented by the Oxmoor sandstone, which includes the Floyd shale of Hayes. This contains irregular beds of nodular limestone, occasionally some chert, and usually has at the bottom one or two beds of massive sandstone, one of which sometimes becomes conglomerate at the extreme southeast exposures in Talledega and Shelby; but for the most part it is made up of black shale. The thickness is from 1,000 to 1,500 feet, being greatest at the southeast.*

The next line of exposures enters northern Cherokee county, Alabama, from Chattooga of Georgia. The conditions in these petty areas are practically the same with those in the southeasterly face of Lookout mountain, a few miles farther north. The Fort Payne is very thin, 25 feet at the southeast, but becomes 250 feet on Lookout mountain, not more than 12 miles away toward the west-northwest. Along this latter line it shows a limestone at the top, very pure, though containing rows of nodular chert. The Bangor is represented by the Oxmoor, which shows no limestone along Lookout mountain, though some irregular but rather persistent beds are seen farther southeast. Sandstones occur at various horizons, but the persistent beds are at the bottom. The thickness varies from 1,000 to 1,900 feet, the increase being toward the northwest. This line of exposures ends near Gadsden, in Etowah county.†

A third line of exposures enters De Kalb county from Dade of Georgia, about 6 miles northwest from the last. It is on the northwest side of Lookout mountain, which it separates from Sand mountain, the continuation of Waldens ridge. This is Wills valley, whence a series of irregular strips extends southwestwardly through De Kalb, Etowah, Saint Clair, Jefferson, Tuscaloosa, and Bibb counties. The Fort Payne varies with some irregularity. It is 200 to 300 feet in De Kalb, 150 to 275 feet in Etowah and Saint Clair, 250 to 300 feet in Jefferson and Tuscaloosa, but diminishes rapidly to 50 feet in Bibb, where, however, the little patches lie somewhat to the southeast of the principal line of exposures. The lower portion is largely chert, with some crinoidal limestone, but the upper portion contains some pure limestone, especially in the northern counties. The Bangor limestone, 500 to 600 feet thick, is present in the northern counties, with massive sandstones at the bottom, but is wanting in Jefferson, where the Oxmoor is present, 800 to 1,200 feet thick, and showing the massive sandstone at the bottom overlying a pure limestone. The condition is the same in Tuscaloosa, except that the limestones seem to be absent. In Bibb county the thickness of the mass

* Henry McCalley: Geol. Survey of Alabama, the Valley regions, vol. ii, pp. 292, 300, 304, 526, 528, 530, 531, 643, 645, 740, 746.

† Henry McCalley, vol. ii, pp. 249, 809 to 812.

‡ Henry McCalley, vol. ii, pp. 172, 183, 184, 245, 249, 300, 304, 410, 422, 476, 478, 504.

diminishes to 600 feet, and some irregular streaks of limestone are shown.

The next important strip is in Browns valley, the continuation of Sequatchie valley of Tennessee, which enters Jackson from Marion of that state. This lies beyond Sand mountain and extends southwestward through Jackson, Marshall, and Blount counties, about 20 miles northwest from Wills valley ; but in Blount county is Murphrees valley, about midway between Browns and Wills, to which reference must be made, as it marks the transition between conditions at the east and those so well marked at the west.

The Fort Payne chert is about 300 feet thick in Murphrees valley, The rather pure limestone already mentioned as occurring at several localities in the upper part of the Fort Payne, here becomes so well marked that Mr McCalley has divided the Fort Payne into the Tuscumbia above, about 175 feet, and the Lauderdale chert below, about 125 feet, these corresponding closely to the Lithostrotion and Protean of Safford in southern Tennessee, the latter being that regarded in the former chapter as equivalent to the upper portion of the Pennsylvania Pocono. Here also the sandstones of the Bangor become so well defined that Mr McCalley sets them off from the Bangor under the name of Hartselle sandstones. Eastward one finds massive sandstones at the base of the Bangor and Oxmoor and at one locality a limestone below them. In this valley sandstones are at the top of the Hartselle, while below them are limestones, shales, and sandstones. The Bangor limestone, as defined by McCalley, is about 300 feet, consisting of interstratified limestones and shales, while the Hartselle is not far from 150 feet.*

Within Jackson and Marshall, in Browns valley, the Fort Wayne is from 225 to 300 feet thick, and the two divisions can be distinguished, though not so sharply as in Blount county where the mass is thicker, the Lauderdale being 175 to 225 feet, and the Tuscumbia 125 to 150 feet. Throughout this valley the Lauderdale is almost wholly chert, while the Tuscumbia consists of cherty limestone. The total thickness of the Bangor is 600 to 800 feet in Jackson and 500 to 600 feet in Marshall, but the sandstone at the base is very irregular. The sandstones may not be the upper but the bottom sandstones of the Hartselle, for in Dorans cove, in northeastern Jackson, there is a 25-foot sandstone at 75 feet below the top of the limestone. In Blount county the Bangor has 300 to 350 feet of limestone and calcareous shale, while the Hartselle is from 150 to 225 feet, with massive sandstones 5 to 80 feet on top,

* Henry McCalley, vol. i, pp. 395 to 407.

a thin sandstone at the bottom, with shales and limestones in the interval. The limestones diminish southwardly. This valley terminates in southwest Blount, nearly 100 miles farther north than the exposures in Bibb county.*

Here one has reached the southern extremity of the eastern exposures; farther southward the Carboniferous is buried under the Cretaceous and later deposits, so that the final conditions in that direction can not be ascertained. On the westerly side of the Plateau area exposures are almost continuous in Alabama, the rocks forming a broad band across the northwestern seven counties of the state and reaching a little way over into Mississippi, the breadth of exposure being due to absence of disturbance. The deep trenching by the Tennessee river near the northern line of the state has removed the upper beds, so that north from that river, in Madison, Limestone, and Lauderdale counties, one finds practically only the equivalents of the Fort Payne, while south from the river, in Morgan, Lawrence, Franklin. and Colbert, only the equivalents of the Bangor occur, underrunning the Coal Measures near the southern border of the first three and the Cretaceous in the last.

Western outcrops in Alabama.—Some deep valleys in western Jackson (on the Tennessee line) reach the Bangor, which shows at from 160 to 200 feet from the top an apparently persistent sandstone, which is probably the upper Hartselle, the limestone below it being cherty. In Madison, just west from Jackson, both divisions are shown fully; the Bangor exhibits abrupt variations, being 200 feet in the northeastern part of the county, but only 100 feet at a little way southeast from Huntsville, while it is 200 feet at the Tennessee river in the southeastern corner of the county, beyond which it passes under the Coal Measures. These abrupt changes and the condition in western Jackson lend countenance to the suggestion that the Dorans Cove sandstone of northeastern Jackson may be the upper Hartselle. The Hartselle in Madison is 150 to 225 feet thick, with a persistent sandstone on top and a thin flaggy sandstone at the bottom, the interval being filled mostly with more or less cherty limestone. All of the sandstones decrease eastwardly, but the upper one persists. In Morgan, south from Madison and west from Blount, the Bangor is thicker, 400 to 425 feet, and portions are as cherty as the Lauderdale, while the Hartselle is from 200 to 300 feet. The sandstones of the latter are thin at the east, but thicken westwardly, the upper bed becoming 100 feet, and the limestones are cherty everywhere. The Bangor is slightly thicker in Lawrence, sometimes reaching 450 feet, while the Hartselle is 300 to 350 feet, the upper sandstone becoming 150 feet and the bottom sandstone 15 feet. In Franklin, west from

* Henry McCalley, vol. i, pp. 307, 309, 320, 360–367, 402, 407, 409, 410.

Lawrence, the Bangor is 350 to 400 feet. In Colbert, north from Franklin, the Hartselle shows unexpected variations; the upper sandstone is apparently 150 feet at La Grange, but it becomes thinner westwardly, for midway in the county are two sandstones, 50 and 25 feet, separated by 25 feet of limestone and overlying 75 feet of sandstone, limestone, and shale; limestone predominates on the Mississippi border, for there the upper sandstones are 30 to 40 feet and 25 feet respectively, separated by 35 to 40 feet of limestone, while lower down are 60 feet of limestone. The bottom sandstones vary from 5 to 15 feet.*

The Fort Payne is very clearly separable into the Lauderdale and Tuscumbia. In Madison both are very cherty and both contain beds of limestone, but the chert of the Tuscumbia is nodular, not bedded. In Limestone the Lauderdale is 175 to 225 feet, and the Tuscumbia 150 to 200 feet, while in Lauderdale the lower division is 175 to 250 feet, with, in the northwest, a thick shale toward the bottom, which disappears southeastwardly. In these counties the Lauderdale becomes more and the Tuscumbia less cherty as one follows them westward.†

Western outcrops in Tennessee.—Professor Safford's notes on the Mississippian of central Tennessee are full and one has in addition, for the southern counties, the résumé of Mr Hayes's observations, and for the extreme northern counties those of Mr Campbell. The exposure with which this chapter has to do forms a broad band crossing the state from south to north through Lincoln, Franklin, Coffee, Warren, De Kalb, Putnam, Overton, and Pickett counties, with extensions eastward into valleys within the Cumberland plateau. This band is separated by the Central Basin of Tennessee from the western area of Mississippian in the state, which is continuous at the south with Lauderdale and Limestone counties of Alabama, and at the north with the western area in Kentucky. The division in Tennessee is wholly due to erosion, and the areas are very nearly united at both the northern and the southern border of the state. As the western area is part of the Mississippi region, which farther north lies west from the Cincinnati peninsula, only incidental reference will be made to it after description of the west side of the Cumberland plateau.

Mr Hayes does not separate the Lauderdale and Tuscumbia—the Protean and Lithostrotion of Safford—using only the term Fort Payne, which includes both. He mentions that the Fort Payne is very silicious at the bottom, often only chert, while calcareous matter increases upward so as to make a gradual transition to the Bangor. The thickness

* Henry McCalley, vol. i, Jackson county, 323, 327; Madison, 140, 144; Morgan, 250, 251, 252, 258, 261, 266; Lawrence, 224, 230, 234; Franklin, 190, 197; Colbert, 154, 157, 161, 166, 176.

† Henry McCalley, vol. i, Madison, 125, 126; Limestone, 115, 119; Lauderdale, 92, 103.

in Franklin and Grundy is not far from 200 feet, but at the north it becomes 225 feet. The Bangor (embracing Hartselle and Bangor of McCalley) is 800 to 900 feet thick at the south, but becomes thinner northward in Grundy and Warren. The upper portion is described as argillaceous and as weathering to bright argillaceous shales—a feature frequently referred to by Mr Hayes in description of the Bangor along the eastern outcrops in this state. No mention is made of any sandstone in Franklin, but in Grundy and Warren a sandstone 15 to 20 feet thick was found at from 150 to 180 feet below the top.*

The work by Mr Hayes enables us to make more intelligent use of Professor Safford's detailed statements. That geologist obtained the following section in Franklin county, near Cowan:

	Feet
1. Shale and some limestone	85
2. Limestone	32
3. Shale and some limestone	70
4. Limestone	214
5. Shales and limestone	26
6. Shale	26
7. Sandstone	8
8. Shale	31
9. Limestone	13
10. Shale	27
11. Limestone	196
Total	704

below which he found about 110 feet of the Tuscumbia (Lithostrotion). The sandstone is here 437 feet below the top as compared with 280 feet in the Sequatchie valley only a few miles eastward. Number 11 shows cherty layers at 80 feet from the bottom, and the Tuscumbia is apparently chert-bearing limestone throughout. The sandstone of the section may be one of the lower Hartselle.†

In White county, northeast from Warren, where Mr Hayes found 700 feet of Bangor, Professor Safford found 601 feet, which shows that the rate of decrease indicated by Mr Hayes continues. The character of the deposit is changing, as appears from the section, which is condensed from the original:

	Feet
1. Limestone	40
2. Mostly shales	115
3. Shales and limestones	70
4. Limestone	123

* W. C. Hayes: U. S. Geol. Survey folios—Sewanee, 1894; McMinnville, 1895.

† J. M. Safford: Geology of Tennessee, pp. 357-358. The section as given is condensed from the original.

	Feet
5. Sandstone	40
6. Limestone	123
Total	601

The sandstone has become thicker and it forms a well defined bench. The limestone is disappearing from the upper portion. The Lithostrotion is 244 feet thick at one locality in this county and contains much chert, which, however, is mostly nodular and much of it is fossiliferous.*

Mr Campbell, in Putnam, Overton, and Pickett counties, northeastward from White to the Kentucky line, finds the conditions similar to those on the east side of the plateau, and reports

	Feet
Pennington shales	90 to 300
Newman limestone	400

About midway in the Newman he finds a sandstone, 40 to 60 feet, shown along the face of the plateau.†

Mr Campbell's average differs somewhat from the section obtained by Professor Safford in the southern portion of the area embraced in the Standing Stone quadrangle, and evidences the continued decrease northward. Professor Safford's measurements are:

	Feet
1. Blue limestone	4
2. Shales, marls, etcetera	52
3. Limestones	154
4. Shales	6
5. Sandstone	48
6. Limestone	168
Total	432
7. Lithostrotion	203

Numbers 1 and 2 probably represent the Pennington shales, which thicken northward at the expense of the limestone, the upper part of number 3 being very largely argillaceous limestone. The sandstone is evidently one of those in the Hartselle, and it was identified by Professor Safford with that seam east from Huntsville in Alabama. The Lithostrotion contains much chert, but the bottom 75 feet is "an impure limestone of water lime aspect."‡

The Mountain limestone of Safford extends westward for only a few miles beyond the Cumberland plateau, so that one finds beyond the

* J. M. Safford: Op. cit., pp. 355–356.

† M. R. Campbell: U. S. Geol. Survey folio, Standing Stone, 1899.

‡ J. M. Safford: Op. cit., pp. 353-354.

Central Basin only the silicious group as in Lauderdale, Limestone, and most of Madison in Alabama. The whole area is bounded at the west practically by the Tennessee river, and the Tuscumbia or Lithostrotion is confined almost wholly to the region north from the Cumberland river. At Clarksville, in the northern part of the area, the Lithostrotion bed shows:

	Feet
1. Not exposed	30
2. Limestone, slightly cherty	15
3. Limestone, no chert, lower third, oolite	120
4. Limestone, more or less cherty	30

The extreme thickness in the northwest corner is about 250 feet, and the limestones contain nodular chert. There is a contrast with the Overton County section, for there the upper 128 feet is largely cherty, while in this western area the chert is insignificant.*

Western outcrops in Kentucky.—In northern Kentucky the Appalachian and Mississippian areas are separated by the Cincinnati peninsula, beyond whose southern termination to the Tennessee line the separation continues, as erosion has removed all rocks newer than the Devonian.

Unfortunately not much of detail is available with reference to Kentucky. The early survey under Doctor Owen ended abruptly with his death, in 1860. Up to that time the work had been very largely that of reconnaissance, and such detailed work as had been done was almost wholly economical, so that the references to Lower Carboniferous deposits are little more than incidental. The same remarks apply almost equally to the second survey, which was prosecuted with much energy to determine as rapidly as possible the coal and iron resources of the state. There is lack of information respecting the limestone, so that one finds difficulty in carrying forward to the Ohio river the differentiation of formations seen so clearly in Alabama and Tennessee. Enough, however, is afforded by the scattered observations in the several counties to make the general conditions clear.

Clinton county of Kentucky adjoins Pickett of Tennessee. Mr Loughridge's section in this county shows the groups as in Tennessee, but with decreasing thickness of the Bangor. His section on Poplar mountain, in the eastern portion of the county, shows—the subdivision and the nomenclature being ours:

	Feet
1. Bangor:	
Shales and marls	130
Limestone	73

*J. M. Safford: Op. cit., pp. 340, 345.

	Feet
2. Hartselle:	
Sandstone	25
Limestone	164
3. Tuscumbia:	
Limestone, cherty	140

The upper portion of the Bangor, as here given, is evidently the Pennington shale of Campbell. Mr Loughridge places the Bangor and the sandstone of the Hartselle in the Chester and the rest of the section in the Saint Louis; but the cherty limestone at the bottom is distinctly the Lithostrotion bed of Tennessee, containing that fossil in abundance, so that it is separated here in order to follow the northward variation more easily.*

Pulaski is northeast from Clinton. There Professor Crandall finds the Chester well exposed in the northern and central parts of the county, where it varies from 25 to 40 feet of earthy limestone with greenish reddish shales. He does not refer to the presence of any sandstone, and gives the Saint Louis as 250 feet thick in the western part of the county, including under this term the equivalents of the Hartselle and Tuscumbia.†

Rockcastle is northeast from Pulaski. Mr Lesley in his notes does not divide the limestone, but gives simply total thicknesses at several localities. He finds it increasing southeastwardly, the measurements being 115, 145, 152, and in the center of the county 182 feet. He suggests that it may reach 220 to 240 feet in the southeast corner, and notes that geodes occur above the lower third, which consists almost wholly of white limestone.‡

Mr Sullivan says that in eastern Rockcastle the "Saint Louis" is from 200 to 210 feet, and his notes seem to show that the "Chester" is absent; but in Jackson county, the next east, he reports the "Chester" as 15 to 30 feet of reddish to greenish shales and argillaceous limestone, separated by 10 to 20 feet of shaly sandstone from the "Saint Louis" below, which is from 225 to 250 feet thick. The upper 25 to 50 feet of the Saint Louis has many flint concretions, but the rest is close-grained whitish limestone.§

Estill county is northeast from Rockcastle. Mr Lyon obtained here a detailed section at about 5 miles from the Kentucky river:

*R. H. Loughridge: Geol. Survey of Kentucky, Report on geology of Clinton county, 1890, pp. 13, 14.

†A. R. Crandall: Geol. Survey of Kentucky, Geology of Whitely county and part of Pulaski county (no date), p. 7.

‡Joseph Lesley: Fourth Annual Report on Geology of Kentucky, 1861, pp. 482-483.

§G. M. Sullivan: Geol. Survey of Kentucky, Geology of parts of Jackson and Rockcastle counties, pp. 6, 7, 18.

	Feet
1. Place of ore beds	
2. Shales	2
3. Limestone	93
4. Limestone with chert	46
5. Earthy limestone	94

The limestone number 3 is mostly earthy, and it might well be described as calcareous shale, if seen only on weathered slopes. Here the "Chester" or Bangor appears to be wanting and the Hartselle and Tuscumbia are sufficiently distinct.*

In Powell county, northeast from Estill, Mr Lesley found a total thickness of 161 feet of limestone. But the limestone quickly decreases, becoming from 30 to 70 feet in Menifee county, according to Mr Crandall, and showing an extreme thickness of 65 feet, according to Mr Linney, in Bath county, where that observer places the whole section in the Saint Louis. Rowan, east from Bath, shows, according to Lesley, only 30 feet of limestone, which is flinty in the lower portion.

Carter county is northeast from Rowan. Mr Crandall's summary notes for this and Greenup county are practically our only source of information, aside from Professor Andrews's fragmentary observations along the Ohio. Mr Lesley's notes are too incomplete to be of service. In southwestern Carter the whole thickness of limestone is 75 feet, while in southeastern Rowan, only a few miles away at the west, it is but 25 feet, showing the rapid decrease westward, which continues until the mass is represented by only a few feet of cherty rock. It increases eastward in Carter county, being 140 feet at Carter's caves, in the central part of the county, though it decreases again eastward, becoming only 40 feet within a few miles. It must increase southeastwardly and be persistent under Boyd and Lawrence counties, for oil-well records in the latter county show a considerable thickness of limestone, as do also those on the West Virginia side of the Big Sandy. Northward from western Carter the decrease is very rapid; 80 to 100 feet of limestone were seen near Boone furnace, in northern Carter, but at Kenton, in west central Greenup, only 10 feet. Farther north the limestone is represented by a few feet of chert or cherty limestone from Schultzes run to the Ohio, in the northwest corner of the county. Eastwardly from this line the distribution is very irregular, for opposite Portsmouth, in Ohio, in the extreme northern part of the county, limestone is wholly wanting, while in the eastern portion, along the Ohio, the limestone is seen again at 5 or 6 miles below Greenupsburg and soon becomes 35 feet, which, however, decreases quickly, so that before the mouth of Little Sandy

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*S. S. Lyon: Fourth Annual Report on Geology of Kentucky, p. 528.

has been reached near Greenupsburg it has disappeared. The detailed section obtained by Professor Andrews below Greenupsburg has been given.*

THE CORRELATION

The Mauch Chunk is represented only by shales, or by shales and sandstones, along the northerly border in Pennsylvania, but southward limestone is found with shale above and below it. This limestone, in the Allegheny Mountain region, reaches to within 30 miles of the northern outcrop, while traces of it are present still farther north in the anthracite region. In southern Pennsylvania it is double, with a silicious division below and a more or less argillaceous division above. The former is the more persistent at the north and in the central part of the basin, but it is wanting in Ohio except in the extreme southeast. Both divisions persist in Virginia, Tennessee, and Alabama, as well as in the greater part of West Virginia and Kentucky. The lower shales become indefinite southward and the upper shales extend as shales little beyond the northern line of Tennessee.

The whole series has been termed Mauch Chunk in Pennsylvania and no special geographical term has been applied there to any of the subdivisions except in the northwestern part of the state, where Dr I. C. White gave the name Shenango to the shale which there is the sole representative of the Mauch Chunk. In Maryland the upper shales have been termed Mauch Chunk and the limestone Greenbrier; in Virginia Professor W. B. Rogers used the names Greenbrier shale and limestone; the United States geologists in that state have applied the names Canaan and Pennington to the shales, Greenbrier and Newman to the limestone; Professor Safford in Tennessee divided the limestone into Mountain limestone above and the Silicious group below, the latter into the Lithostrotion and the Protean, of which the former belongs to the Mauch Chunk; to Professor Safford's divisions Mr Hayes applies the designations Bangor and Fort Payne, with, in the southeastern areas, Floyd as equivalent to the lower portion of the Bangor; in Alabama the limestone is divided by Smith and McCalley into Bangor, Hartselle, and Tuscumbia; in Kentucky the divisions are Chester and Saint Louis, and in Ohio, Andrews termed it the Maxvillle.

The reader who has followed the details given in the preceding section has seen that the Alabama divisions are traceable northward for a long distance.

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*A. R. Crandall: Geol. Survey of Kentucky, Report on the geology of Greenup, Carter, and Boyd counties and a part of Lawrence. Reprint of reports, vol. C, 1884, p. 6

Beginning at the south on the western outcrop, one finds, ascending, the Tuscumbia, limestone and markedly silicious; the Hartselle, sandstone with shales and limestones; and the Bangor, limestones more or less argillaceous. These three divisions retain their characteristics across Tennessee into Kentucky, the Bangor meanwhile becoming more argillaceous in northern Tennessee, where its upper portion has been identified with the Pennington shale. In Kentucky the Tuscumbia and Hartselle are taken together as the Saint Louis, but they retain the Tennessee features, one of the Hartselle sandstones being persistent. The Bangor becomes very shaly, and, like the Tuscumbia, thins out northward more rapidly than the Hartselle, so that the last alone is present in central Ohio, where Professor Andrews called it the Maxville.

Along the eastern outcrop, one finds greater variation, for outlying areas toward the southeast reveal something of the conditions existing along the old shoreline. But those areas may be neglected in this connection. Following the border of the principal areas, one finds the Tuscumbia, Hartselle, and Bangor sharply defined in Alabama, with the same features as on the western side. In Tennessee the Tuscumbia is easily recognized in the upper portion of Mr Hayes's Fort Payne, while at least one of the Hartselle sandstones is persistent into southern Virginia; but the Bangor, the upper portion of Mr Hayes's Bangor limestone, becomes increasingly argillaceous northward, so that frequent reference is made to its tendency to weather into shale. Toward the Virginia line it becomes almost wholly shale and sandstone, while it increases greatly in thickness, so that Mr Campbell has separated the Pennington shale from the limestone which he calls Newman. The enormous increase in thickness of the section, due to increase of land detritus, renders exact tracing difficult for a little way in southwest Virginia, the more so since detailed descriptions have not been published. The Bangor evidently becomes wholly shale and sandstone before New and Greenbrier rivers are reached, where Fontaine and Campbell found so great a mass of shales with insignificant streaks of limestone. The persistence of the Hartselle sandstone at the bottom of the shales or near the top of the limestone is shown by many of the oil records and along the outcrops almost into Pennsylvania. The upper limestone of Virginia, Maryland, and Pennsylvania is the Hartselle. The Tuscumbia retains its silicious character throughout, though losing its chert in Virginia and becoming merely a silicious limestone; this feature, along with a curiously current-bedded structure and a peculiar whiteness when crushed, characterizes it thence into Pennsylvania, where by several of the geologists it was termed the Silicious limestone.

The correlation seems to be :

Shenango.—Bangor of McCalley in Alabama; upper portion of Bangor of Hayes in Tennessee; upper portion of Safford's mountain limestone in Tennessee; Chester of Kentucky geologists (second survey); Pennington and top of Newman of Campbell in Tennessee and southwest Virginia; Umbral shales of Fontaine; Canaan shales of Darton; Greenbrier shale of W. B. Rogers; Mauch Chunk shale of Maryland; Mauch Chunk of Pennsylvania in part; absent from most of Ohio; Shenango shale of I. C. White in northeast Ohio and northwest Pennsylvania.

Maxville.—Hartselle of Alabama; greater part of Bangor in Tennessee; lower part of mountain limestone in Tennessee; greater part of upper Newman and of upper Greenbrier in Virginia; upper Umbral and upper Mauch Chunk limestones in Pennsylvania; Maxville of Ohio; upper Saint Louis of Kentucky.

Tuscumbia.—Tuscumbia of McCalley in Alabama; Lithostrotion of Safford in Tennessee; upper part of Fort Payne in Tennessee; lower part of Saint Louis in Kentucky; lower Newman and Greenbrier in Virginia; lower of Greenbrier in Maryland; silicious limestone of Pennsylvania; absent in Ohio except at Kentucky border.

The term Shenango is the earliest applied definitely to the latest division. Though Doctor White's Shenango shales have been spoken of as representing the whole of the Mauch Chunk sedimentation, it will be shown in the next chapter that they represent practically only the sedimentation of the closing epoch. The name Maxville was given by Professor Andrews in 1870, and therefore antedates Hartselle by many years. Tuscumbia, being a geographical term, will have to replace the much older Lithostrotion of Professor Safford.*

The fossils from the Shenango appear to be those characteristic of the Chester of the Mississippi basin. Forms belonging to that epoch have been collected in Pennsylvania, Virginia, Kentucky, and elsewhere. Fossils collected by Andrews in 1869 from the Maxville localities in Ohio and by Stevenson in 1870 from the same limestone in West Virginia were submitted to Mr F. B. Meek, who pronounced them distinctly Chester. Professor R. P. Whitfield afterwards figured and described the Ohio forms, referring them practically to the same horizon. Still later,

* In the preceding chapter the writer has given reasons for rejection of the name Catskill, and he has conceded that owing to confusion in the use of Chemung, that name also might be discarded. In the latter case, however, he entertains some misgivings, as the difficulty lies rather in disagreement respecting boundary lines, and he can not grant that because a term has been used to designate two formations which are consecutive it should be cast aside, any more than he could grant that a generic term in biology should be rejected because in the original description it included forms which proved afterwards to belong to several genera. This has been conceded by those who are apparently urgent in introducing new names without any regard to priority, for Greenbrier and Mauch Chunk have been retained, both of which have been used as comprehensively as either Hamilton or Chemung. In the immediate instance Shenango is definite. Its boundaries are clear, and it should be retained in preference to the cacophonous Mauch Chunk, which, if retained at all, should be used merely as equivalent to the Genevieve of Professor H. S. Williams.

in 1901, Stevenson collected carefully at a locality in Fayette county of Pennsylvania and submitted the specimens to Mr Weller, who found that the fauna contains some Saint Louis as well as the Chester forms. There is, however, practically no change in the fauna from the bottom to the top of this locality, the same forms, with two or three exceptions, being found throughout. The Chester forms predominate, and of those belonging to the Saint Louis some lived on into the Chester at typical localities within the Mississippi basin. The same fauna occurs in Randolph county of east central West Virginia and in Washington county of Virginia at the Tennessee border. In Tennessee and Alabama the Maxville (Hartselle) is clearly Chester. The Kentucky geologists of the second survey make the Maxville the upper part of their Saint Louis, but it overlies the Lithostrotion bed, the lower part of their Saint Louis. No list is given of the fossils which lead to classification of the limestone as Saint Louis.

The Tuscumbia is practically non-fossiliferous at most localities in Pennsylvania. In Tennessee and Alabama, as well as in Kentucky, *Lithostrotion canadensis* is the characteristic fossil, and it is associated with other forms belonging to the Saint Louis.

Physical Changes during the Mississippian

THE LATER DEVONIAN

The several deposits have been traced throughout the basin in such detail as available observations permit. It remains to ascertain, if possible, what geographical changes and stratigraphical disturbances took place during the Mississippian, but it is necessary first to make reference to conditions existing during the later Devonian.

Dnring the Chemung (Jenning) the area of sedimentation extended from the Appalachian shore westward across Pennsylvania into northern Ohio; across Virginia and West Virginia, evidently to the Ohio river; southward from the line of central Virginia the area contracts. There appears to be no Chemung in Kentucky, none in Tennessee, except on the eastern side of the basin, while in Georgia it is confined to a narrow strip following the old shoreline. The Chemung basin was very broad at the north, reaching far into New York and crossing into northeastern Ohio, but it tapered southward, the contraction being on the westerly side, until it disappeared in Georgia. The area of more rapid subsidence, lying near the old shoreline, was narrow throughout, reaching north, from New river of Virginia, to only a few miles beyond the Alleghany region. The vast thickness observed along the eastern border decreases so quickly in southern Pennsylvania that before the

Alleghenies of that state have been reached the mass has become diminished one-half, while in central western Pennsylvania the section is barely one-fifth as thick as in Fulton county of the same state; and in Ohio the deposit becomes thin and recognizable only with difficulty. Southward from New river the rate of subsidence decreased and the trough became narrower. At 125 miles beyond that river the great mass has become only a few hundred feet thick even on the edge of the Great valley, and the deposits appear to reach not very far into Tennessee; but outlying areas show that the rapidly tapering trough continued into northwestern Georgia and possibly into Alabama.

The material of the Chemung deposits is fine grained throughout, with the exception of two conglomerates, very persistent along the eastern border to beyond New river in Virginia, but becoming somewhat finer westward, where they are the first and third oil-sands of Pennsylvania. The advent of the Catskill (of Vanuxem, Hampshire of Darton) was marked by physical changes which gave to that formation a good claim to recognition as a natural group. The area of sedimentation became contracted so as to coincide rather closely with the Chemung area of chief subsidence. Eastwardly it extended as far as did the Chemung, but westwardly it reached not more than 30 miles beyond the line of the Alleghenies of Pennsylvania, while southwardly it became shallower to the shoreline, which lay apparently in Montgomery county of Virginia. Western Pennsylvania, eastern Ohio, almost the whole of Kentucky, West Virginia, and Tennessee received no deposits, so that there was land or water too shallow to receive any deposit all the way from the Cincinnati peninsula almost to the line of the Pennsylvania Alleghenies. That the basin was wholly landlocked southward is not probable, for the writer obtained *Spirifer disjunctus* from the upper beds near Salem, Virginia, not very far from the last traces of Catskill toward the south. Throughout the Catskill the deposit is fine grained, mostly mud and muddy sandstones, with red and green as the prevailing colors. Toward the close a conglomerate appeared at the northeast, which, however, extends but a short distance southwestwardly.

The Chemung conditions were restored and exceeded at the close of the Catskill, and deposits belonging to the later Devonian (Lower Pocono, Cuyahoga, etcetera,) show that the area of sedimentation gradually encroached upon the land, west and south, so that they finally covered the whole basin north from the Tennessee line, thus overlapping the Chemung at the west and northwest. Southward from the Tennessee line the basin contracted on the westerly side and very quickly was confined to the area of eastern Tennessee and northwest Georgia where there seems to have been a deep arm of the sea during the Chemung and latest De-

vonian. The deposits are in contrast with those of the Chemung and Catskill; at the east they are for the most part sands, often very clean, at times coarsely conglomerate. The lowest bed is conglomerate, most markedly so along the easterly outcrops, but more or less so at localities in western Pennsylvania and northern West Virginia. The transition from the Catskill is abrupt but not absolute, for red beds occur at many localities in eastern Pennsylvania, while in the north central part of that state green is the characteristic color of many sandstone beds. The material grows finer westward, the thickness varying slightly beyond the Alleghenies, and in northwestern Pennsylvania thin calcareous beds make their appearance, one of which may have been persistent southward in West Virginia.

Throughout the Chemung and Catskill the land must have been subsiding at the east; the streams were approaching nearly to baselevel and only fine material was brought down. Two interruptions occurred, during which were formed the Chemung conglomerates.

The extreme subsidence had been reached in New York as early as the beginning of the Chemung, and the streams brought down mud and fine sand, in great part containing so much iron as to be colored red or green. As the subsidence of the mainland became marked farther and farther south, the red and green beds covered a greater area, and in the Catskill one finds those beds to the southern limit of the formation. It is worthy of note that the *Amnigenia catskillensis*, which in the Catskill Mountain region began its existence in the lower Chemung, gradually moved southward, so that before the close of the Catskill it had reached the southern border of Pennsylvania. As the change in Chemung rocks had become complete at the end of that period, one may imagine that some relation may have existed between the great sinking of the Appalachian land and the elevation of land on the western side, by which the Catskill trough was narrowed.

The Catskill was closed by an elevation in the Appalachian region, rendering the streams more or less torrential, so that the last period of the Devonian was opened by the deposit of coarse rocks. Answering to the eastern elevation was the western depression, so that the subsidence and amount of deposit was almost as great in Ohio and Kentucky as in Pennsylvania and the most of Virginia. Southward the subsidence continued far beyond the limits of the Catskill and possibly beyond that of the Chemung.

As already stated, the Catskill may have been almost landlocked. The absence of salt in the beds, which otherwise recall in many ways the Salina of New York, and the almost total absence of marine life seem to suggest that during the greater part of the Catskill sentimenta-

tion most of the area was covered with a shallow depth of fresh water; but marine conditions returned during the latest Devonian.

THE LOGAN

At the beginning of the Logan the Appalachian land north from Tennessee is rising and the whole basin, except along the northern border, is subsiding gently, so that the sea encroaches on the land westward and southward.

East from the Alleghenies of Pennsylvania the Logan conditions are shown imperfectly, for even the anthracite outliers are at a long distance from the old shoreline. The rocks for the most part are coarse sandstones, with thin shales and very thin coal beds. This is the condition in northern Virginia, but southward in that state the outliers are found still farther eastward, some of them even in the Great valley and within a few miles of pre-Cambrian. There the rocks are finer and the coal beds thicker, so as to be of local importance, though the coal is usually very impure. Still farther south the coal beds disappear, calcareous rocks appear, and eventually the silicious matter is in the form of chert beds, interstratified with thin limestones.

Beyond the Pennsylvania Alleghenies sandstone with no coal is the prevailing rock in the most of Pennsylvania, as well as in West Virginia, to probably 30 miles south from the Baltimore and Ohio railroad, meanwhile becoming replaced by shale below until at last, in central West Virginia, the whole interval is occupied by shales, extending downward into the Devonian for hundreds of feet, a condition continuing even into Kentucky. This change in character takes place at practically the same latitude as on the eastern outcrop. In Tennessee and Alabama, within this central part of the basin, the conditions resemble those on the eastern outcrop. In northwestern Pennsylvania the lower portion is shale and contains an impure limestone. No trace of this limestone appears in oil-well records of western Pennsylvania, but the records of wells in portions of Harrison and adjoining counties in north central West Virginia note the local development of limestones directly under the " Big Injun " or Logan sandstone.

Still farther westward, along the outcrops in Ohio and Kentucky, as well as under cover in those states, the conditions are strikingly in contrast with those of the Devonian. The mass thickens rapidly southward and southwestward in Ohio. For about one hundred miles from the Pennsylvania border it is fine grained above and coarse below, but along the western outcrop for many miles it is distinctly and almost constantly conglomerate, though evidently thinner than at the north. The pebbles are flat, small, and nearly uniform in size. Irregular limestones occur,

very thin, but persisting for considerable distances. The massive structure and great thickness characterize the Logan under cover in southeastern Ohio and eastward to Roane county of West Virginia, where it is replaced by the shales to which reference has been made. In southern Ohio, however, the coarseness diminishes, and in the upper Knobstone of Kentucky one finds only fine grained sandstone, which in turn grows finer and more shaly until in Tennessee the Lauderdale character is assumed, which prevails in western middle Tennessee and in northwestern Alabama. There is, then, a sandstone deposit crossing the northern portion of the basin, extending southward almost to the central line of West Virginia; on the west side this extends southward into Tennessee, but on the east side hardly any farther than in West Virginia; the south central portion of the basin almost to Tennessee is occupied by shales. From both sides the deposit grows finer toward the central line of the basin.

The form of the area of sedimentation differs from that of the latest Devonian. It seems hardly possible that the Logan extended northward into New York except at the extreme northeast; its limit in northern Ohio is far south from that of the Cuyahoga, while its western limit in that state could hardly have been very far beyond the present line of outcrops; but southwardly the area widened until beyond the Cincinnati peninsula it became broadly continuous with sediments of the Mississippi area. On the eastern side the boundary can have been little different from that of the Devonian as far south as the Tennessee line. Southward the latest Devonian overlaps the Catskill by many miles and is in turn overlapped by the Logan, which reaches into central Alabama, overlapping even the Chattanooga black shale, which may represent the Hamilton of New York. The southward expansion of the area was very gradual; for while Kinderhook, Burlington, and Keokuk occur in northwest Pennsylvania and Ohio, the lower members disappear southwardly in succession, so that in northwestern Alabama only the Keokuk appears to be present. The rate of subsidence must have been practically the same in by far the greater part of the area, contrasting in this respect notably with prior times, for from Cambrian almost to the close of the Devonian a great trough of subsidence lay along the old shoreline at the east.

The source of material found along the westerly outcrop is very uncertain. The rocks of earlier periods on that side are fine grained, very largely calcareous or argillaceous; even the Berea sandstone is very fine; yet for a long distance the Logan is largely conglomerate and the sandy deposit continues much farther southward on the west than on the east side. The pebbles of quartz are small and flat, as though chafed

long on a low shore. They can hardly have come from the north, for there the upper Logan, Reid's Olive shales, is very fine in grain, while farther south it becomes coarse as it is in northwest Pennsylvania, east from Reid's localities. It is equally improbable that the pebbles came from the east, for the deposits become finer eastward toward the central line of the basin, beyond which they become coarser. The sands must have come from the western side.

THE TUSCUMBIA

The Tuscumbia is represented in the northern portion of the basin by shale and the overlying silicious limestone.

The limestone is present, though indefinite, within the anthracite fields and is distinct in the Broad Top and Fulton County outliers. According to Mr Meyer, quoted by Professor Lesley, it is present in the Allegheny area as far north as Lycoming county; only a trace remains in Clinton, the next west, and there appears to be none in Center, south from Lycoming. The boundary passes westwardly from Blair across Indiana into Allegheny; thence across northern Washington into West Virginia; crosses the Ohio river below Wheeling into Ohio; reenters West Virginia near Saint Mary's and passes a little way east from Parkersburg; there bending, it crosses southeast Ohio to the Ohio river and enters Kentucky just beyond the western border of Greenup county and continues thence irregularly southwestwardly until it curves around the Cincinnati peninsula. East and southeast from this irregular line, which is very nearly the original shoreline, it is persistent in the main area as well as in outlying areas, except those of Montgomery county, Virginia, though very attenuated in those of Pulaski and Wythe in the same state.

It is difficult to determine, by means of available observations, whether or not the Fort Payne of the extreme southeasterly areas embraces any Tuscumbia. For the most part the features are those of the Lauderdale (Logan), there being an almost total absence of limestone in the upper part; but in Calhoun county of Alabama, very near the extreme southeast exposure, one finds the Tuscumbia clearly present. One may conjecture that as the Lauderdale is practically without limestone nearer the shoreline the Tuscumbia would undergo the same change, so that the thin Fort Payne on the border would represent both. This is in accordance with the conditions in this region, as each of the Mississippian formations apparently overlaps its predecessor; but for the present the question must remain unanswered.

The Tuscumbia limestone is absent from the whole of northwestern Pennsylvania, about 15,000 square miles; from almost the whole of eastern Ohio, and is very irregular in distribution within eastern Ken-

tucky, where, however, the available observations suffice for an approximation.

A shale underlies the limestone in some portions of the basin. It appears to be persistent in the Anthracite strip, but in the Allegheny region its presence is doubtful except in Lycoming county. It is absent in the greater part of that region in Pennsylvania as well as under the Laurel and Chestnut anticlinals; but oil-well records prove its presence in western Pennsylvania along a narrow strip southward from Butler county almost to the West Virginia line. It is present in Pocahontas county of West Virginia and is recorded occasionally in wells of that state. Usually it is overlapped by the limestone, but in the strip within western Pennsylvania it evidently extends farther north; the shale may have had greater eastward extension in the anthracite fields, but no positive assertion can be made, for in those fields the results of the first and second geological surveys are not wholly in accord respecting the limestones or, better, the calcareous beds.

It is very evident that at the close of the Logan the trough of sedimentation was greatly contracted on the north and west, and that in some portions of Pennsylvania, where the limestone is present, there was dry land at the beginning of the Tuscumbia, for in a large area within the central portion of the state the shales are wanting. Local foldings of slight extent must have been very numerous, as shown by the absence of the shales in so many localities within West Virginia.

The most northerly point of the basin during deposition of the limestone was apparently midway in the northern anthracite field. The rate of subsidence increased southwestwardly, as in that direction the thickness increases, being greatest in the Cumberland Plateau region—equivalent closely to the Alleghenies of Pennsylvania, which shows also that as in the Logan the axis of greatest subsidence lay somewhat west from that for the Devonian. Whether or not the encroachment of sea on the land continued at the southeast can not be ascertained at present. Tuscumbia is clearly present in Calhoun county, Alabama, within 3 or 4 miles of the extreme Fort Payne outcrop at the southeast. Tuscumbia appears to be recognizable at the extreme southern exposures in central Alabama.

Almost as far south as Tennessee, in the eastern and middle portions of the basin, the Tuscumbia limestone is very arenaceous, weathering to a sand. Fossils are extremely rare, but those which have been found are marine. The continuity of the calcareous deposit was interrupted for a short time, during which a sandstone, very coarse at one locality but ordinarily very fine, was laid down over a great area. The peculiar current bedding of the limestone, thoroughly characteristic, is suggestive

of shallow water. The irregularities in thickness, as shown in the West Virginia records, seem to show that the subsidence was associated with petty crumplings of the beds.

THE MAXVILLE

In the Anthracite strip of Pennsylvania the Maxville has not been recognized north from the Broad Top area, where the impure limestones above the main deposit have been taken as its representative. As these limestones thicken southwardly at the expense of the shales, the latter to some distance above the impure beds should be taken as Maxville. Such shales make up a great part of the section in the southern and middle anthracite fields, but in the northern field it is doubtful if they extend as far north as Scranton, for the deposits there and northward are of the Shenango type. There is not much reason to suppose that Maxville deposits of any sort extend northward beyond the central line of Pennsylvania in the Allegheny region, since in Blair county the whole of the Mauch Chunk is but 283 feet, while in Center county it is estimated at not more than 150 feet, whereas in Broad Top, only 30 miles east, the Shenango and Maxville are 910 feet. In western Pennsylvania, as shown by exposures under Laurel and Chestnut hills, as well as by oil-well records, the northern limit is not far beyond the line of the Conemaugh gaps, considerably south from that of the Tuscumbia. It is barely possible that the western boundary crosses into the Panhandle of West Virginia, but in any event it lies near the Pennsylvania line and passes southwardly across Wetzel county of West Virginia, through western Doddridge into Gilmer, where it turns westwardly into Wirt, central Wood, and Jackson, from which it passes into Ohio. No well records in the latter state have been published, but the line evidently bends northwardly, for the Maxville limestone outcrops in Perry, and it has been found in eastern Muskingum, whence Andrews followed it into Kentucky, where it is the upper part of the Saint Louis. Thence southward it is recognized easily as the lower part of Safford's Mountain limestone and as McCalley's Hartselle.

Along the eastern outcrop in the Allegheny region the Maxville limestone increases slowly southward to beyond the Potomac; but farther west, under the great anticlinals of southwest Pennsylvania and West Virginia, it increases rapidly, becoming important commercially before reaching the line between those states. The mass thickens and becomes more calcareous southwardly, attaining its greatest thickness in the region of the Virginia Alleghanies or even farther eastward—that is, in the equivalent of the Pennsylvania Anthracite strip. One must remember, however, that the Maxville is hardly to be considered as limestone

in by far the greater part of this area. It is very calcareous, but it contains few beds pure enough for lime, the most of it being calcareous shale or argillaceous limestone, with varying beds of sandstone. The greatest mass of comparatively pure limestone appears to be in the Cumberland Plateau region of Tennessee, approximately on the line of the Pennsylvania Alleghenies.

The outlying areas in Virginia, Tennessee, Georgia, and Alabama show the influence of near-shore conditions. The Virginia areas, within the Great valley, have no limestones, only shales and sandstones being present; whether or not any portion of these represent the Maxville could not be determined. The Maxville is certainly present in the Chilhowie mountains of east Tennessee, in the most easterly exposures within Georgia, as well as in those of Alabama to the last exposure at the south; but in all of these it is no longer an impure limestone with sandstones and shales, but a mass of shales and sandstones, the former often carbonaceous, with occasional thin beds of limestones; and this mass attains great thickness where it overlaps the Tuscumbia. Even on the western side in Alabama the same condition exists, for there the sandstones and shales predominate in the Hartselle. It is possible that some of the overlying Bangor limestone belongs to the Maxville.

The conditions during the Maxville differed in some respects from those during the Tuscumbia. The area of sedimentation was more contracted on the northern and western sides, for no deposits were made in northwestern West Virginia. It is altogether probable that in the early part of the period much of central Pennsylvania received no deposit, for there and in adjoining part of West Virginia one often finds a breccia above the silicious limestone, consisting chiefly of fragments of that rock. But while so much of the area was above water at the beginning and so remained throughout the period, there was a subsidence in southeastern Ohio, gradually extending northward, forming a bay reaching into Muskingum county, so that along the outcrop from Muskingum southward one finds lower beds appearing until the Tuscumbia is shown before the Kentucky line has been reached, and in like manner, under cover, before the West Virginia line has been reached. Under cover in West Virginia the oil records show great irregularities within the counties bordering on the shore area—sometimes apparently only the upper beds, at others only the lower beds are present—and one is led once more to suggest local crumplings and disturbances as the only explanation.

At the east one finds evidence of continued lowering of the mainland and of continued advance of the sea upon a low shoreline. The deposits at the north were of fine material even to the Allegheny line, with very little calcareous matter; and this continued all the way to

the last exposures; but the landward advance was much more marked at the south, where the thickness of the sandstones and shales is very great, even where the Tuscumbia and Logan have almost disappeared, while in Alabama the advance was so great as to push the shore evidently almost to the fall-line of the streams, for there the sands are coarser and in such quantity as to be the characteristic feature from central Alabama northward to within 50 miles of the Tennessee border on the western side of the area; which leads to the supposition that the land area southward and westward was much greater than has been supposed. The outlet to the ocean may have been in Tennessee.

The water area at the close of the Maxville extended farther south and west than at any time after the middle of the Upper Silurian, for the Maxville overlaps the whole Devonian and even the earlier members ef the Mississippian. The greatest thickness is in the equivalent of the Pennsylvania Anthracite strip, though it does not coincide with that of the Devonian. Apparently the depth of water was not considerable in any portion, except possibly in the Cumberland plateau of Tennessee, for at most localities the limestone is very impure and the deposit was interrupted several times by sandstones.

THE SHENANGO

The Shenango overlaps the Maxville in Pennsylvania and reaches northward, almost to the line of New York. At the west it barely crosses the Ohio line and the boundary lies but little beyond Pennsylvania to the southern line of that state. In West Virginia the Shenango is wanting in Wetzel, Tyler, Pleasants, Ritchie, most of Doddridge and Wood counties, is very thin in the northern Panhandle, and is very irregular in many other counties of the state. The Maxville underlies the Coal Measures directly in Ohio, and in Kentucky the western limit of Shenango is at some distance east from that of the Maxville. In western Pennsylvania, as shown by oil-well records, the Shenango is very thin, rarely exceeding 100 feet and often wanting. Even in the Allegheny area of that state it is insignificant, the whole Mauch Chunk section varying from 75 feet in Tioga to 300 feet in Blair, and apparently not much more in Somerset county; but farther south, under the Briery Viaduct axis, White found 370 feet, while on the Potomac it is not less than 650 feet. In the Anthracite strip it is 75 feet at Scranton, and increases southwardly to about 600 feet or more in the southern field.

Under West Virginia, along the line of the Pennsylvania Allegheny and westward it decreases rapidly, but along a line somewhat farther

east, that of the Alleghenies of Virginia, it increases, being 1,250 feet in Pendleton, 1,260 feet in Greenbrier, and 2,500 feet in Summers, the greatest thickness being apparently in the vicinity of New river. In the Great valley of Virginia and on the border of the Cumberland plateau, in the southern part of the state, it is about 1,100 feet. Westward it thins rapidly along the whole line, and everywhere to the northern border of Tennessee it is shale or sandstone with a little limestone; but in Tennessee, on both sides of the main area, the shales become thinner, more calcareous, and at length become limestone, so as to be included in the Bangor limestone of Mr Hayes. The upper beds persist as shale much farther than do the lower.

The outlying areas in Georgia show the limestone of the later Maxville (?) and Shenango extending far to the southeastward, overlapping the Floyd shales or Oxmoor sandstone of that region; but at the south it appears to be replaced wholly by sandstone, the Oxmoor there being regarded by the Alabama geologists as representing both Maxville (Hartselle) and Shenango (Bangor).

So, toward the close of the Shenango, the water-covered area occupied Pennsylvania, Maryland, Virginia, central Tennessee, northwestern Georgia, and northern Alabama west from the Blue Ridge line, but practically none of northwest West Virginia, of Ohio, and in Kentucky less than during the Maxville. The subsidence in Pennsylvania and West Virginia west from the Alleghenies was insignificant and very slow, the main trough of sedimentation lying eastward from the Allegheny region. The subsidence extended southward so as to permit the Shenango to overlap the Maxville in Georgia and Alabama as it does at the north. The character of the sediment north from Tennessee, almost invariably red shale or muddy sandstone, shows a continued depression of the mainland at the east, while the same condition for the south is shown by the overlapping of the earlier members of the series.

The four subdivisions of the Mississippian—the Logan, the Tuscumbia, the Maxville, and the Shenango—are characterized by definite boundaries, due to physical changes, involving for each the whole basin.

CONVEX SURFACE (FRONT) OF ALGOMA METEORITE

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 14, PP. 97-116, PLS. 3-7 APRIL 17, 1903

METEORITE FROM ALGOMA, WISCONSIN

BY WILLIAM HERBERT HOBBS

(*Presented before the Society July 1, 1902*)

CONTENTS

HISTORICAL

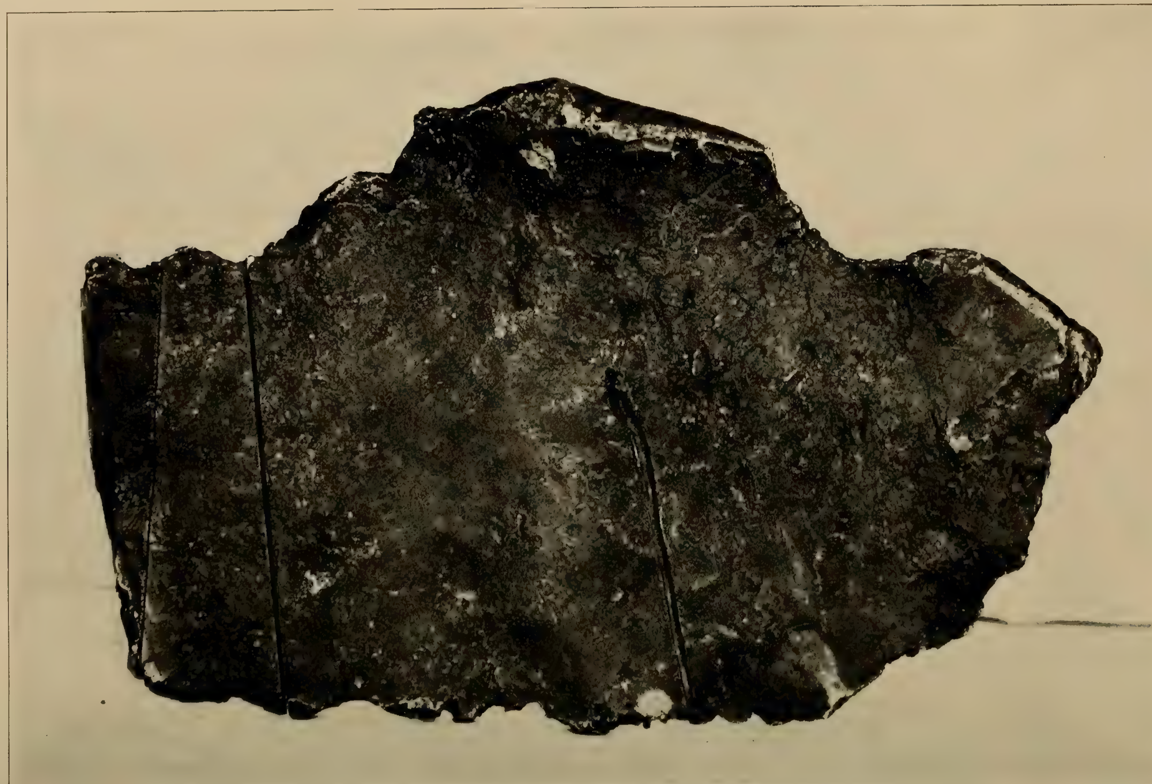
The meteoric iron which is here described was plowed up in the spring of 1887 on the farm of Mr Henry Runke, about 4 miles west of Algoma

post-office, Ahnapee township, Kewaunee county, Wisconsin. The man who was guiding the plow noticed the heavy metal as it was turned up by the plow from the depth of but a few inches. Mr Richard Runke, son of the farmer, was present and reports that the hired man placed the object upon a large stone and struck it a number of blows with another stone used as a sledge, in an attempt to break it. The evidence of this maltreatment it bears in a series of dents, especially upon its convex surface (*a a*, figure 1; see also plate 3). Subsequently it was vigorously attacked with cold chisel and hammer (see especially the groove upon its concave side, plate 4). A curiosity merely, the Algoma iron remained about the farm on which it was found until March of the present year (1902), when Mr Richard Runke, now a graduate of the University of Wisconsin and teacher of science in the Madison High School, brought it to the writer for examination. On being told that it was a meteorite and of considerable scientific value Mr Runke very generously presented it to the university.

The spot at which the meteorite was plowed up can be located within a few feet, because of its proximity to a large pile of boulders upon the lot. Mr Runke has made some search in the vicinity and has also made extensive inquiries among the neighbors, but as yet with no positive results. As will be shown below, there was reason to think that fragments might exist in the vicinity and the search was continued with the aid of dial compass and dip needle, but without success.

Size and Shape

Instead of the usual irregular form or the paraboloid shape of some oriented meteorites (Hraschina, Allegan, Long Island), the Algoma iron is almost unique in having a discoid or shield-like form. In the surface of greatest extension the outline is roughly elliptical, with major and minor axes 25 and 16½ centimeters. From a thickness of about 2½ centimeters near the geometric center the disc varies irregularly, generally to smaller values and locally even to a knife edge at and near the circumference (see plate 6, figure 1). The convex surface in the plane of the minor axis of its outline and its normal has a radius of curvature of about 21 centimeters and the concave surface a considerably larger value, about 32 centimeters. The two broad surfaces are spoken of as the convex and concave surface respectively, because the former invariably recedes near its margin (though concave at one place and in one plane near its center). The other surface is more nearly concave than



CONCAVE SURFACE (BACK) OF ALGOMA METEORITE

convex, and in one plane (that of the minor axis and the normal) is distinctly concave.

Weight and specific Gravity

When brought to the university, the Algoma iron weighed a little less than 9 pounds, or somewhat more than 2 kilograms (weighed with a spring balance). A small slice, in the widest place less than 3 centimeters in width, was sawed from one end, and due to a misunderstanding of instructions a saw-cut was made, running partly through the meteorite at a greater distance from the end (see plate 4). After suffering these losses the main meteorite mass now weighs 3,716 grams.

A block weighing a little over 39 grams, polished on two sides, after boiling in water for half an hour and cooling to room temperature, was weighed in the water, and then, after drying, in air by the suspension method. The result obtained for the specific gravity was 7.75.

Surfaces

THE CONVEX SURFACE

Larger irregularities—The convex surface, for reasons which will appear, designated the front of the meteorite (*Brustseite*), merits a careful consideration. Marks which this surface owes to its maltreatment subsequent to its discovery in 1887 are the dents (*a a*, figure 1) from pounding with a sharp rock edge, the grooves (*b b*, figure 1, and *c c*, figure 2), from attack with a cold chisel and hammer, and the abraded surface (*c*, figure 1) and scratches (*d*, figure 1) which are the work of a file. In addition to these disfigurements there are larger surface features of two kinds. At *e* and *f* (figure 1) and less prominent at *g* are relatively deep pits of markedly irregular outline which doubtless owe their origin to the fusion and removal of a mineral (schreibersite) more fusible than the nickel-iron itself. The manner in which such pits are formed is well illustrated by the small pitting cut through by the saw and shown in plate 7, figure 1, at the bottom of which may be seen the schreibersite crystals separated by walls of swathing kamacite. The pit at *e* (figure 1) corresponds in position with a similar pit upon the back of the meteorite (*b*, figure 2), and doubtless was once continuous through the disc, as it may now be followed nearly through and appears to be choked for a short distance by the oxide scale which lines its walls.

The low fusibility of schriebersite is well known and was well brought out during the polishing of the section, the smaller crystals of schreiber-

site at once revealing their position by their fusion, due to the moderate frictional heat of grinding.

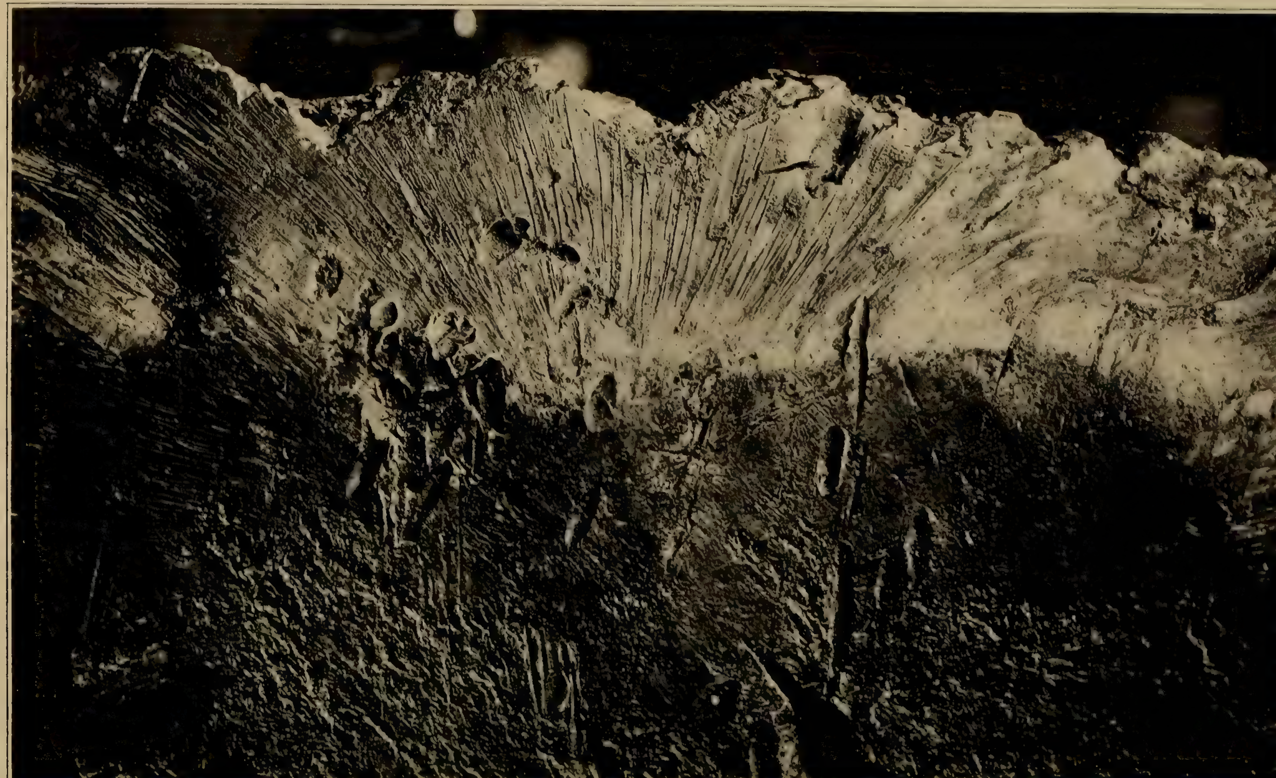
The larger shallow pittings at *h* and *i*, which more resemble the conventional "thumb marks," have doubtless been produced in a similar manner by fusion of schreibersite, combined with fusion and abrasion of the outer walls, since their sides toward the meteorite center possess the same steep, irregular slopes as the others, with some accumulation of oxide scale. Being located near the circumference of the disc, they lie within the zone of maximum erosion from the action of the compressed

FIGURE 1.—*Diagrammatic Sketch of Meteorite's convex Surface.*

Designed to serve as a guide to plate 3. The area outlined by the dotted line is the nearly flat central boss. The spirally radial lines of the margin are ridges and grooves, and their lævorotatory character is somewhat exaggerated in the sketch. *a a*, dents due to pounding with a rock at the time meteorite was discovered; *b b*, grooves produced by attack with cold chisel; *c*, a portion of the margin abraded by a file; *d*, file scratches; *e*, *f*, *g*, deep pits produced by fusion and removal of schreibersite; *h* and *i*, "thumb mark" pittings due to fusion of schreibersite in the marginal zone of erosion (larger in plate 5); *j*, saw-cut stopped by encountering schreibersite; *k l* and *m n*, saw-cuts.

air, and the thin walls which presumably once separated them from the present circumference of the meteorite would be hardly able to withstand the erosive action.

The marginal area of the meteorite front, on which the pittings *h* and *i* are found (for convenience called the straighter margin) is in rather sharp contrast with the opposite front margin (the lobate margin). From the nearly plane central boss of elliptical shape (axes, 9 and 7 centimeters) the surface of the disc slopes away sharply on the side of the larger pit-



ENLARGED VIEW OF PORTION OF CONVEX SURFACE OF ALGOMA METEORITE

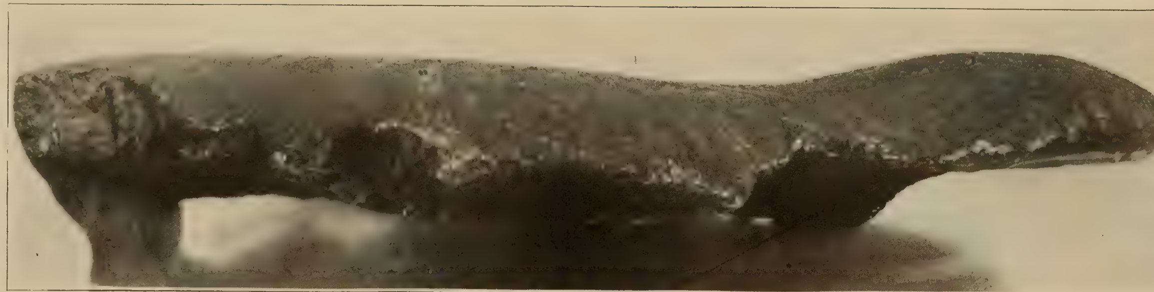


FIGURE 1.—THE LOBATE EDGE

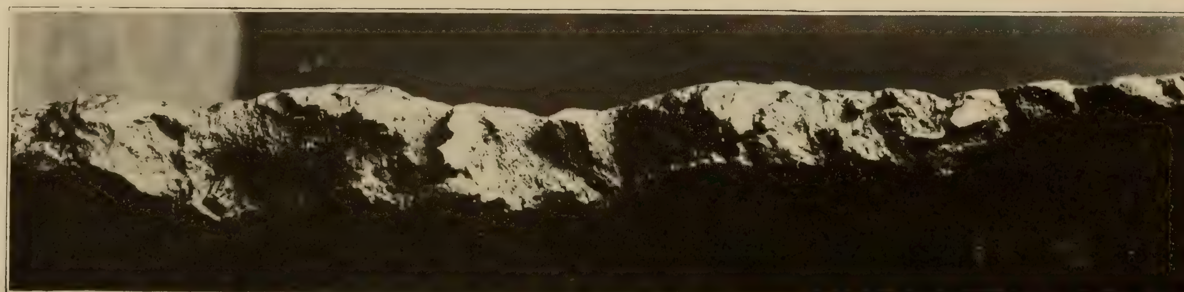


FIGURE 2.—THE STRAIGHTER EDGE, SHOWING RUPTURE SURFACE

MARGINAL SURFACE OF ALGOMA METEORITE

tings and is there also deeply furrowed in directions nearly radial. The lobate side recedes in more gradual curves, is marked by small and irregularly distributed pittings, and is covered with a thin film of oxide. Through this coating of oxide the nearly radial furrows and ridges which characterize the opposite margin can be followed without difficulty, though they are much less distinct, and the effect produced is altogether like that which would be expected if this side had lain in a moist soil while the other had received greater protection. The margin not covered by the oxide (that of the shallow pittings) shows a steely, metallic luster. Near the ends of the front the surface resembles that of the margin where the shallow pittings are found. The end opposite the saw section, however, projects to the front from the margin of the central boss before its surface recedes in the regular curves characteristic of other parts of the front (see plate 6, figure 1). This suggests that the meteorite may have been bent in about its geometric center by a force acting normal to its surface.

The central boss of the front shows even under the lens little trace of the radial furrows, and then only in circumferential portions. On the straighter side, where the surface slopes away rapidly from this boss, the furrows begin with great distinctness at the line where the flat boss gives place to the backward slope.

Drift ridges and furrows.—The radial markings could perhaps better be described as ridges than as furrows; they are in reality the material left in sharp, knife-edge lines between very shallow furrows having nearly flat bottoms. The ridges have a basal thickness of a fifth to a tenth of a millimeter, and where best developed the intervening furrows widen from about a millimeter at the margin of the central boss to two millimeters at the present circumference of the meteorite. Approximating to right lines the ridges appear to have been modified in their direction to some extent by the crystalline structure of the meteorite, but even where deviated from their initial direction the tendency to maintain rectilinear directions is apparent. They sometimes cross one another at extremely acute angles (see plate 5). Interesting radial drift phenomena have been described by Tschermak and Döll on the meteorite from Mocs.*

While at first sight the ridges would appear to be strictly radial, closer examination, especially when made by stretching a fine thread along them, reveals the fact that they are in reality slightly curved in a

* Tschermak: Ueber die Meteoriten von Mocs. Sitzungesber. Akad. Wissensch., Wien., vol. 85, 1882, p. 195.

Döll: Zwiei neue Kriterien für die Orientirung der Meteoriten. Jahrb. d. k. k. geol. Reichsanst., vol. xxxvii, 1887, pl. vi.

common direction, the radius of curvature diminishing as the circumference of the meteorite is approached. They represent, therefore, the arms of an Airy's spiral. This variation from a straight line is approximately 1 in 30 or 1 in 50, and is greatest where the slope from the central boss is the steepest. In only one instance was any variation from the common direction of curvature to the left (lævo-rotation) observable, and this was in the bottom of the larger of the two marginal pits, where for a short distance the curvature is reversed only to resume its regularity near the edge of the disc (see upper part of plate 5).

Surface markings due to crystalline structure.—Beneath the prominent drift scorings the lens seldom fails to reveal the crystalline structure of the metal in regular cross-linings of lesser prominence. These show to the best advantage in the bottom of the deepest marginal pit on the side nearest the center of the mass—in the "lee of the wall" of that side.

Fracture lines.—Perhaps in some way connected with the crystalline structure is the series of parallel cracks which course over the front of the meteorite in a direction about parallel to its greatest cross-diameter. These joint-like cracks are observable by the unaided eye, and can doubtless be made out in plate 3. Their direction is more clearly indicated in figure 1. In places they are crowded together, separated by rather uniform space intervals of 1 to 2 millimeters, and at times they are lined with oxide, especially on the more oxidized side of the front.

THE CONCAVE SURFACE

"*Thumb marks.*"—The generally concave surface of the meteorite, as already explained, is in sharp contrast with the convex surface or front. In general aspect it does not differ from the surface of the greater number of meteoric irons, and may be described as undulating, due to the presence of large and very shallow pits ("thumb marks") which coalesce with one another.

Oxide scale.—Over all this surface of the meteorite is a coating of oxide of iron which varies in thickness from less than ½ to about 1 millimeter in thickness. Thickest on the side of the most protected hollow of the surface, it has scaled off locally and left a series of irregular depressions on the larger pittings of a second order of magnitude (see plate 4). As this edge is the one which corresponds to greater oxidation upon the front, it is probable that some small portion of the oxidation occurred subsequent to the fall, due to the unfavorable conditions for preservation as regards air and moisture.

On this surface of the meteorite there are no distinct markings observ-

able which can by any probability be ascribed to erosive agencies within the aerosphere.

Infolding of edges.—Of some interest is the apparent folding back of the edges on the concave surface (see *a a*, figure 2, and plate 4). This infolding of the edges appears to have been before observed, and is quite noticeable on the models of the meteorites from Puquios, Chile, and Rancho de la Pila, Mexico. The regular curving of both surfaces of the

FIGURE 2.—*Diagrammatic Sketch of Meteorite's concave Surface.*

Designed to serve as a guide to plate 4. *a a*, *a a*, edges folded back; *b*, deep pit caused by fusion of schreibersite from the convex side (*e* of figure 1); *c c*, groove produced by a cold chisel; *d*, *d*, approximate margins of shallow thumb marks; *e e*, saw-cut extending partly through meteorite (*j* of figure 1); *k l* and *m n*, saw-cuts.

Algoma meteorite near the edges that are turned back favors the view that this phenomenon is a result of slight bending of the marginal area from the pressure of the compressed air on the front, the greater curvature of the front (over that of the back) being ascribed to the erosive action (see figure 3).

THE MARGINAL SURFACE

The marginal surface of the meteorite in all cases where the front does not meet the back in a sharp line has a very hackly appearance and indicates with little doubt a fracture surface. The more irregular contour of the disc along its margin is for about half its length rounded off by the curved front surface meeting the thumb-marked rear surface (see plate 6, figure 1). Elsewhere, however, it has just the appearance of the fracture surface of a malleable metal ruptured by tensile stresses, small

fibers or horns of metal being still attached to the surface (see plate 6, figure 2, and plate 7, figure 2). The small V-shaped notches in the marginal contour are rather striking, and perhaps indicate that there was a shearing component of the stress by which the metal was ruptured. A very thin film of oxide quite unlike the scale upon the back covers the marginal area of fracture.

Composition and Texture

CHEMICAL COMPOSITION OF METEORITE

The chemical analysis of the Algoma iron was kindly undertaken at my request by Mr Arthur A. Koch, laboratory assistant in quantitative analysis at the University of Wisconsin. Duplicate analyses were made of samples of 5 grams each. The material used for this purpose was in thin plates from the sawed cross-section.

On dissolving in acid, evaporating to dryness, and redissolving, the residue was very slight. After weighing, this residue was treated with hydrofluoric acid, and no gritty substance remained. The analyses yielded results as follows, the iron being in the one case determined by the gravimetric and in the other by the volumetric method:

	1	2
Iron	88.60	88.64
Nickel	10.64	10.62
Cobalt	.77	.91
Phosphorus	.14	.16
Silica	.02	.02
Sulphur	Trace	Trace
Copper	None	None
Carbon	None	None
	100.17	100.35

WIDMANNSTÄTTEN FIGURES—THE TRIAD

The Algoma meteorite is an octahedral siderite rich in kamacite and taenite and relatively poor in plessite. The kamacite bands are of three types: First, there are the relatively thick bands (.6 to 1 millimeter) which cover the space of the section in a fairly regular network; second, there are parallel series of perfectly contiguous finer bands (.1 to .5 millimeter) or *Kämme*, which completely fill the large areas (Cohen's *Gescharrter Kamazit*) (see plate 7, figures 1 and 2), and, lastly, there are the swathing bands about schreibersite (*Wickelkamazit*), which are usually of exceptional width and generally swollen and irregular as regards outlines (see especially plate 7, figure 3). Gradations between these varieties

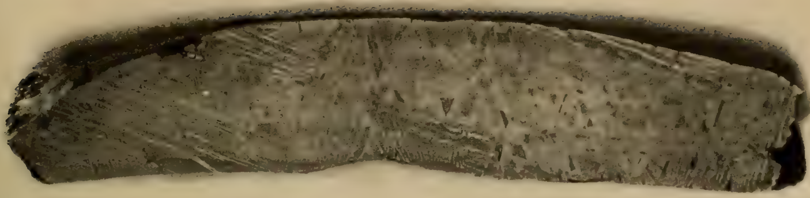


FIGURE 1.—WIDMANNSTAETTEN FIGURES. MAGNIFICATION ABOUT 1 : 1

FIGURE 2.—THE SAME ON A DIFFERENT SURFACE. MAGNIFICATION ABOUT 1 : 1.33

FIGURE 3.—ANOTHER SURFACE, SHOWING *Wickelkamazit* ABOUT SCHREIBERSITE

FIGURE 4.—NEUMANN LINES. MAGNIFICATION ABOUT 10 DIAMETERS

ETCHED SURFACE OF ALGOMA METEORITE

occur, but the first two types are nevertheless very clearly marked in the general structure. The *Wickelkamazit* frequently, though not always, produces a merely local swelling of the coarser bands. Taenite in jagged, irregular, and occasionally interrupted lines surrounds the kamacite of all types (see plate 7, figure 1). The plessite is of the structureless variety (*Fleckiger plessit*).

NEUMANN LINES

The kamacite bands when etched to any considerable depth reveal beautiful Neumann lines (*Schraffirter Kamazit*), as shown in plate 7, figure 4.

REICHENBACH'S LAMELLÆ—SCHREIBERSITE

The schreibersite, which is prominent on etched surfaces by reason of its brilliant luster and its great susceptibility to oxidation, is arranged in rather distinct lines within the kamacite (Reichenbach's lamellæ). Always enveloped in kamacite, the largest area within the principal section (see plate 7, figures 1 and 2) has a wide aureole of kamacite about it. Being at the front surface of the meteorite, its fusion on one side has produced a noticeable depression on that surface. The hardness of this mineral was at the limit for the band saws used in cutting, even small areas of schreibersite sufficing to break them, and the hardness and brittleness were, moreover, serious obstacles in the way of securing well polished surfaces for etching. The analysis shows that schreibersite comprises about 1 per cent of the entire mass of the meteorite. The mineral is developed in relatively thin plates, often of considerable size. The one which figures in all the sections (see plate 6, figures 1, 2, and 3) was also encountered in the saw-cut which extends partly through the meteorite at a distance of 2 to 4 centimeters from the sawed end (see *e e*, figure 2), and must therefore have been not less than 3½ or 4 centimeters in length. The small branches of this crystal exhibited in plate 6, figure 2, conform to the Reichenbach lines.

The fractures noticed on the front surface of the meteorite are seen in section on the forward margin of the etched surfaces as local, small dark lines extending into the mass for a depth of 1 or 2 millimeters. These are evidently filled with an oxidation product (perhaps the "*Eisenglas*" of some authors).

Owing to the markedly swollen character of the kamacite bands (*Wulstiger Kamazit*), it is difficult to determine whether any slight distortion, such as would be induced by bending of the disc, has occurred. It can hardly have been more than a few degrees at the most, since the general direction of the bands is well maintained across the section.

From the above it is clear that the Algoma iron belongs in the Charlotte group and is in many respects similar to Cohen's Charlotte type, which fell in Charlotte, Dixon county, Tennessee, in 1835. In all the respects of coarseness of structure, proportions of the members of the triad, varieties of kamacite and plessite, Neumann lines in kamacite, fractures and their fillings, resistance to weathering, Reichenbach's lamellæ, and their distribution in the network, it seems to correspond very closely; and one of Brezina and Cohen's plates * would fairly well represent the Algoma iron. In composition also there is but slight variation. Both irons are remarkably free from the elements not constituting the triad. Algoma has 10.5 as against 8 per cent of nickel; Charlotte has .06 per cent of copper, which is not found in Algoma, and the latter has .15 per cent of phosphorus, which is absent in the former.

THEORETICAL—MANNER OF FLIGHT

BROADSIDE ATTITUDE IN TRANSLATION

There seems no reason to doubt that the Algoma meteorite moved broadside on during its flight through the aerosphere, such being required by the well demonstrated laws of mechanics, albeit contrary to common notions. The principle referred to is illustrated whenever a card or disc falls by gravity against air resistance, and is in fact brought out whenever a discoid body moves against air resistance from any initial attitude other than that which opposes the broadest surface to the air pressure. In this attitude the air currents will wrap about the disc, following the lines of least resistance. The body is urged forward by a force (its momentum or gravity) whose resultant is applied at its center of mass—its center of form. The resultant of the pressure of compressed air is applied at a point some distance from the center of form toward the end of the disc which is in advance. A couple is thus induced tending to erect the body into a position normal to its line of flight. If carried by this couple beyond the normal position, as it inevitably would be, a reverse couple is set up, so that a pendular vibration would precede for a longer or shorter interval its attitude of perfect erectness normal to its path.

Little attention seems to have been given to the manner of flight of meteorites, probably because few investigators have had to deal with definitely oriented bodies, and, with two recently described exceptions, none appear to have been mentioned which possess a flat form in any degree approaching that of Algoma. As long ago as 1861, however,

* Die Struktur und Zusammensetzung des Meteoriesens, plates xvii and xviii.

v. Haidinger, describing the flat meteoric iron from Agram, takes account also of the inevitable rotation, and concludes that such a body would be driven flat side forward. He says:

"Hat erst die Rotation begonnen, so muss sich, sobald Verlangsamung des Zuges eintritt und die Rotation rascher wird, auch der Zweit schwerste Punkt in die Rotationsebene stellen, so dass eine flache Eisenmasse wie die von Agram gerade zu flach vorwärts getrieben wird."*

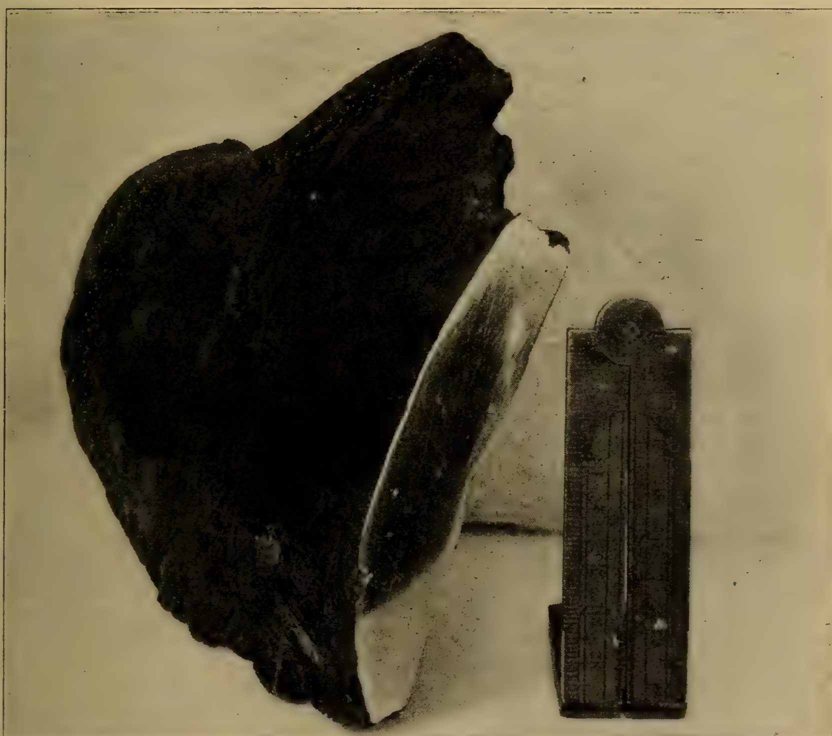


FIGURE 3.—*Perspective View of Algoma Meteorite.*

Showing its discoid shape. The sawed surface has been polished but not etched.

EVIDENCE OF SIMILAR ATTITUDE OF N'GOUREYMA IRON

Cohen has recently described in much detail the flat meteorite from N'Goureyma, in the Soudan, Africa,† which, as regards its shape and sur-

*Ueber die Natur der Meteoriten in ihrer Zusammensetzung und Erscheinung. Sitzungsber. Wiener Akad., Math. naturw. Kl., vol. 43 (Abth. ii), p. 405.

†Das Meteoreisen von N'Goureyma unweit Djenne, Provinz Macina, Sudan, von E. Cohen. Mitth. naturw. Verein f. Neu-Vorpommern u. Rügen, vol. 33 (1901), pp. 1–15.

face markings, offers many analogies with the Algoma iron. It is, however, less symmetrical on both the broad and the narrow sections, and its weight is thus concentrated to one side of its center of form, but it is distinctly a thin oblate or discoid meteorite of the same general type as the Algoma iron. Cohen was led, from the study of its surface markings, to the conclusion that it moved forward with its thin edge inclined at a sharp angle to its path, but from personal correspondence I learn that he does not now attach special weight to this.

On the convex side of N'Goureyma the metal has been fused and has flowed in radial directions, and its surface is also locally furrowed in these directions. On the flatter and more concave side the photogravures published with the article and the beautiful photographs from which they were made (kindly submitted to the writer for examination) show only the faintest of grooves or lines, and these are found only near the periphery, where they are radial. What to the writer seems the strongest evidence for a broadside attitude during its flight is the presence on the concave side of very marked groovings on the outer side of two openings through the stone from front to back. These furrows are as perfect as any which are found upon the front, but they are restricted to the area pheripheral to the two openings. They indicate, it would seem, that the compressed air, against whose enormous pressure the meteorite was opposing its convex surface, moved off that surface in radial directions, and escaping in part through the orifices, eroded those portions of the back which lay between the orifices and the circumference of the disc.

It is not impossible that at some period of its flight the now concave side of the N'Goureyma meteorite may have been the front, and the faint radial markings upon the back have been then induced. At all events, the removal of material from its now convex side may have altered its shape materially, as Cohen indeed assumes.

Professor A. G. Greenhill, the distinguished mathematician of the Ordnance College at Woolwich, was sent a photograph of the front of the Algoma iron. He has very kindly written to the author upon the subject, and says of the meteorite: "It illustrates very clearly the stability, without rotation, of an oblate body moving in fluid in the direction of its shorter axis. An elongated prolate body requires rotation for stability, as we know in the artillery of rifled guns." It should be mentioned that the slight curvature of the furrows upon the front of the meteorite is hardly perceptible in the photograph, owing to the inclined position in which the object was photographed.

The Arlington iron from Minnesota is also of the flat type. This iron has, according to Winchell,* dimensions in its plane of greatest extension

*Am. Geologist, vol. 18 (1896), pp. 267–271.

of 12 to 15 inches, and an average thickness of ½ inch. It has a convex and a flat or plane side, and hence falls in the class of shield-shaped meteorites with Algoma and N'Goureyma. Like them, its convex surface is the smoother and the flat surface has a scale of oxide best preserved in the depressions. Winchell does not, however, discuss the manner of flight of the Arlington iron.

CURVATURE OF DRIFT FURROWS INDICATES LÆVO-ROTATION

The curvature of the radial scorings on the front of the Algoma iron indicates with little doubt that it possessed or acquired a lævo-rotation about its principal or shorter axis, which, in view of the stability of such a body without rotation may be ascribed to an initial velocity of rotation about this or some near-lying axis when the body arrived at the margin of the aerosphere. At my request, Professor Slichter has investigated this problem from the standpoint of mechanics, and found that a discoid body entering the aerosphere under initial rotation will at once begin a precession and thereafter "go to sleep" after the manner of a top, rotating about its principal (shorter) axis. Thus, initial rotation and forward translation alike require a perpendicular attitude of the disc to the air which it is traversing. Professor Slichter's discussion of this subject follows immediately upon the conclusion of this article.

PROBABLE RUPTURE OF ALGOMA IRON DURING FLIGHT

The hackly marginal surfaces of the Algoma iron indicate, it is believed, the remnants of original fracture surfaces brought about by failure (rupture) under tensile stresses. It is inconceivable that they should have suffered so little from the compressed air, which has eroded the front of the meteorite, except on the supposition that they were produced in a late stage of the flight through the aerosphere. It is also a reasonable supposition that the high velocity of rotation of the body and the decreasing strength in the marginal portions, owing to the ever increasing erosion in those portions, brought about rupture from the centrifugal force of rotation. It appears to be a soluble problem, though doubtless a difficult one, with this supposition to determine the dimensions of the disc in its plane of greatest extension before the peripheral portions were thrown off.

CAUSE OF "THUMB MARKS"

From the foregoing it is clear that the Algoma meteorite exhibits three distinct surfaces, representing as many periods of formation—the undulating, oxide-covered back, with its shallow thumb marks ; the con-

vexly eroded front, with its radially spiral ridges and furrows, and the hackly fracture surface of the margin. Of these surfaces the back most resembles the surface of the greater number of meteorites, is presumptively the one less affected by the flight through the aerosphere, and its main features may be said, with little doubt, to date from the pre-ærospheric period of the body. The convex front was doubtless formed, so far at least as its present surface is concerned, entirely within the aerospheric period, while the hackly marginal surface doubtless represents a later phase of the same period, since the erosion of the front ends not gradually, but abruptly, at its edge.

Emphasis should be laid on the fact that the back of the meteorite appears to have come to us but little affected except for its scale of oxide, by the flight of the body through the aerosphere. Formation of a scale of this nature is so common on the back of oriented meteoric irons that conditions in the wake of the meteorite must be assumed to be especially favorable to such formation.

Much has been written regarding the cause of the peculiar thumb marks of meteorites. In the light of the recent investigation of Chamberlin,* which shows that small meteoric bodies may be broken apart through stresses induced by the near approach of larger bodies, a satisfactory explanation may perhaps be found. The probability also that meteoric bodies travel in swarms, which has long been recognized, has received a valuable confirmation in the investigation of Högbom.† He has plotted the known falls of meteorites according to the days of the year, and finds that those which fell at about the same time of the year are remarkably similar in composition and texture. Goldschmidt ‡ has shown that the result of the impingement of stony particles upon a rock surface, as illustrated by the desert stones abraded by wind-blown sand, is to produce a surface almost identical with that of certain thumb-marked meteorites.

From a consideration of the above evidence it would seem to the writer that a possible explanation of the thumb-marked surface of many meteorites may be found in the irregular surface produced by rupture of a larger meteoric body subsequently abraded by the smaller meteoric particles as it is drawn toward the earth out of the swarm in which it was found. The greater number of the smaller bodies would doubtless be vaporized, to reappear as the meteoric dust so commonly observed in snow-covered regions. This hypothesis ascribes the main features of

* On a possible function of disruptive approach in the formation of meteorites, comets, and nebulæ. Jour. Geol., vol. 9 (1901), pp. 369–392.

† Eine meteorstatistische Studie. Bull. Geol. Inst. Univ. Upsala, vol. 5 (1901), pp. 132–143, pl. iv.

‡ Ueber Wüstensteine und Meteoriten. Tschermak's min. u. petrog. Mitth., vol. 14 (1894), pp. 3–13, pls. i, ii.

the surface to the pre-aerospheric and the early aerospheric periods of the meteorite, in which it seems most likely that they were formed.* It agrees well also with the theory of meteoritic structure and composition recently stated by Farrington,* a theory which must appeal strongly to all students of petrography as being most in accord with the facts obtained from a study of terrestrial rocks.

In accord with this view is the important observation of Döll,† who, after an examination of a large number of oriented meteorites, of meteorite models, photographs, and published descriptions, lays stress on the fact that depressions are much less common on the front than on the back of meteorites, and that on the back they are broad and shallow conchoidal depressions, either coalescing with one another of separated within the general surface of the back—a structure which Hoernes ‡ has likened to that of the surface of some melting masses of iron, and Nordenskiold § to the cavities in melting icebergs. On the front of meteorites the cavities when present are more irregular and oval in shape, with their longer axes radial, and they have generally steep walls on the side toward the center of the meteorite front. To the writer these observations of Döll are interpreted to indicate that the irregularities on the meteorite back were formed at a higher temperature in a general melting down of the body during its pre-aerospheric period; the irregularities upon the front, on the other hand, to fusion during its passage through the aerosphere, the steep walls toward the center, as in the case of the Algoma iron, being the contact planes of included more fusible metals with their host. Furthermore, the reddish brown oxide scale, which so generally covers the back of oriented meteorites and is missing from their front, must be assumed to be formed within the aerospheric period, to which the presumably lower temperature behind the moving body is favorable.

Acknowledgments

In conclusion, acknowledgment should be made of the able assistance of Professor Charles S. Slichter, who has so well supplemented this paper by his discussion of the problems of flight of the discoid meteorite within the aerosphere, problems which seem to have been overlooked in the study of meteoric bodies. To Mr Arthur A. Koch the writer is indebted

* The pre-terrestrial history of meteorites. Jour. Geol., vol. 9 (1901), pp. 623–632.

† Döll: Zwei neue Kriterien für die Orientirung der Meteoriten. Jahrb. d. k. k. geol. Reichsanst., vol. 37, 1887, pp. 200–201.

‡ Hoernes: Ueber den Meteorsteinfall bei Ohaba, etc. Sitzungsber. Akad. Wissensch., Wien, vol. 31, 1858, pp. 79–84.

§ Nordenskiold: Ueber drei grosse Feuermeteore, Zeitsch. Deutsch Geol. Gesel., 1881, p. 14.

for the chemical analysis, and to Professor A. C. Scott, of the Rhode Island Agricultural College, at present Honorary Fellow of the University of Wisconsin, for some very successful photographs. To Mr Richard Runke, who supplied the material for study and who has devoted considerable time to search for separated fragments of the meteorite, the University of Wisconsin and the writer have been placed under obligation. From the Field Columbian Museum and Professor O. C. Farrington, the curator of its collection of meteorites, the writer has received many courtesies.

Appendix: Discussion of the Motions of a Discoid Meteorite; by Charles S. Slichter

In the following discussion the attempt is made to explain by simple and well known principles of mechanics the motions of the Algoma meteorite after it had reached the earth's aerosphere. It is assumed that the meteorite arrived at the outer limits of the air with a high velocity of translation and a high rate of rotation about its shortest principal axis. According to the well known laws of motion of a rigid body, only two of the three principal geometrical dimensions of the meteorite would be stable axes of rotation, namely, the longest and the shortest of its geometrical axes. The meteorite being thin and flat in shape, the directions through the center of mass in which an initial axis of rotation could lie and result in stable rotation about the long axis are exceedingly limited in range, so that rotation about the long axis would be very unlikely, even early in the history. We must therefore suppose that rotation took place about the axis of greatest stability, which is the shortest axis of the body. If the meteorite were not so flat and elongated it possibly would not be so essential to suppose that its rotation was about its shortest axis. We must also assume that the axis of the meteorite made an angle θ with the direction of its path, whose value, when the aerosphere was reached, may have been any chance amount whatsoever.

We shall first consider the distribution of the pressure of the air upon the surface of the meteorite. The lines of motion of the air particles past the moving meteorite are shown approximately by the curved lines in figure 4.

This drawing is based on a diagram of Lord Rayleigh,* who has presented the results of a mathematical investigation of the stream lines

*See Kirchoff: Zur Theorie freier Flüssigkeitsstrahlen, Crelle, vol. lxx, 1869; Lord Rayleigh: On the resistance of fluids, Phil. Mag., December, 1876; Lamb: Hydrodynamics, 1895, pp. 94, 109–111.

near a plane lamina moving in a perfect liquid. The points D and D', where stream lines terminate on the surface of the meteorite, are points of no motion. D is a point of maximum pressure and D' is a point of minimum pressure, for which reason the air is concentrated in a dense mass in the neighborhood of D, while a partial vacuum surrounds D'. The high pressure at D and the low pressure at D' evidently result in an accelerating couple tending to turn the disc, in the case represented in the diagram, in the direction of the hands of a watch.

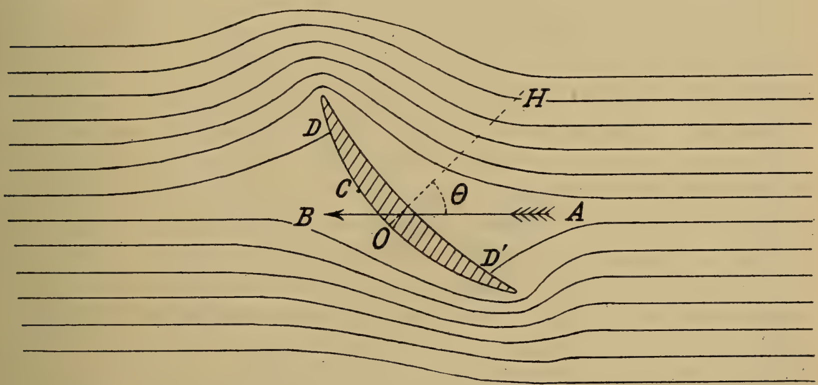


FIGURE 4.—*Diagram showing Stream Lines about Discoid Body projected into the Aerosphere.*

A B, direction of translation; *O*, center of mass; *H*, principal axis; *θ*, angle between principal axis and path of meteorite; *C*, center of pressure; *D D'*, points of no-air motion in reference to disc.

Rayleigh has shown that for a plane lamina moving in a perfect liquid, the center of pressure—that is, the point at which a single force could be applied which would exactly balance the total pressure exerted by the liquid—is situated at a distance from the center of the lamina

$$\bar{x} = \frac{3}{2} \frac{\sin\theta}{4 + \pi\cos\theta} l$$

in which $2l$ is the width of the lamina and θ is the angle between the direction of motion and the normal to the lamina. The maximum value of this expression is readily found to be

$$\bar{x}\max = \frac{3}{8} l$$

which means that the distance of the center of pressure from the middle of the lamina cannot exceed an amount equal to three-eighths of the semi-width of the lamina. This limit would be different for a discoidal

meteorite moving in the atmosphere (which is, of course, a viscous gas and not a "perfect liquid"), but these numbers will suffice for the present argument. Since the momentum of the body is applied at the center of mass O, while the resultant pressure is applied at the center of pressure C, the direction and magnitude of the resultant couple are dependent on the relative position of these two points. In a symmetrical body, as represented in figure 1, the direction of the couple will be as above described. If the body be irregular in shape, so that the center of mass is farther than three-eighths of the semi-diameter from the geometrical center of the body (as for example in a body shaped like a tadpole), then the couple in question will act in the opposite sense and will tend to turn the body into the air stream and not abreast of it.

The effect of the accelerating couple just described on the motion of the rotating meteorite is easily ascertained. The result is identical with the influence of gravity on a spinning top or gyroscope, a result commonly designated as "precession." By the well known laws of rotating bodies, an angular acceleration applied about an axis intersecting at right angles the axis of rotation sets the spinning axis of the body in a new position in the plane of the two axes and toward the axis of acceleration. If the angular acceleration be continually applied (as in the case of a common top), the spinning axis will describe a cone, called the cone of precession. The rotating meteorite, upon striking the aerosphere, must therefore have taken up, as it progressed along its path, a motion of precession entirely similar to that seen in a common top. The rate of precession would be dependent both upon the velocity of translation and the rate of rotation, increasing with the former and decreasing with the latter magnitude.

Following the inauguration of the precession, the next phenomenon in the meteorite's motion would be a continuous and rapid lessening of the angle of the cone described by the precessing axis. This phenomenon s also readily explained by the properties of a common spinning top. If in the case of a top or gyroscope we artificially hasten the precession, the top will rise toward a vertical position; if we slow the precession, the top will fall. This principle is really no different from that which explains the motion of precession. In each case an accelerating impulse applied to a rotating body with one point fixed, but otherwise free, produces a motion at right angles to the direction of the impulse.

In the case of a common top the explanation of the gradual rise of the axis of the top toward the vertical (the so-called "sleeping" of the top) may be readily inferred from figure 5, A. This figure represents on a much enlarged scale the blunt point of the top in contact with floor, the

section $N\ O\ M$ being equivalent to a minute wheel on which the top rolls. This wheel, on account of the rapid rotation of the top, acts like the driving wheels of a locomotive, propelling the top and accelerating the precession, resulting therefore in a rise of the axis and the " sleep " of the top. Precisely similar conditions are present in the case of the meteorite. In this case the " floor " on which the rotating body spins is an elastic one, and consists of the dense air near the point D (figure 1), at which the air pressure is a maximum. Therefore the meteorite no sooner takes on its motion of precession than the rate is augmented by the rolling of the meteorite on the cushion of dense air, resulting in a " sleep " of the meteorite. This explains why the body must pass through the air with its flat face presented broadside to the resisting medium.

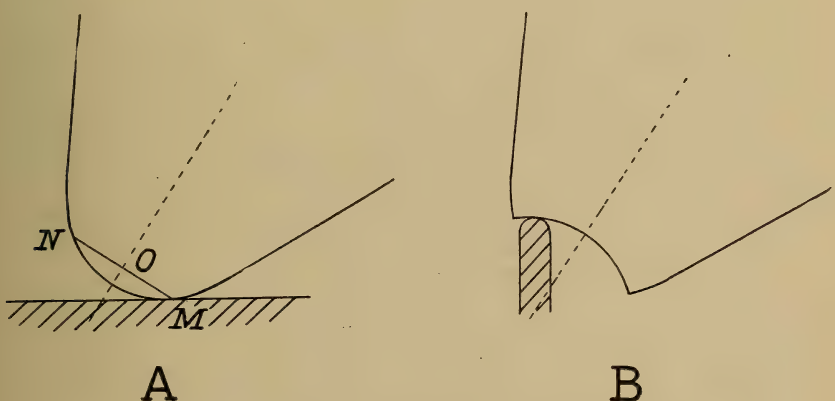


FIGURE 5.—*Diagrams illustrating Movements of Spinning Top.*

A = diagram illustrating the blunt point of a top spinning on the floor ; B = diagram illustrating a top with hollowed apex spinning on a pointed standard.

The curvature of the face of the meteorite would have important effects on the position of the center of pressure. If the convex side were the front or the side toward the earth, the effect of the curvature would be to increase the distance of the center of pressure C from the middle point O. If the concave side were in front, then the center of pressure would be moved toward O, and if the concavity were sufficient, the center of pressure would pass to the other side of O, and the meteorite would be reversed, the convex side passing to the front. Hence unless the curvature was very slight, the convex side would be the one which would constitute the front side of the meteorite. Figure 5, B,

illustrates corresponding conditions in the case of a top. If the point of a top be hollowed out, as shown in the figure, and then spun upon a pointed standard, the result will be a continuous slowing up of the precession and the fall of the top. The conditions are just reversed from those shown in figure 5, *A*, in which the precession is hastened by the rolling of the blunt point on the floor.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 14, PP. 117-132, PLS. 8-13 APRIL 18, 1903

PACIFIC MOUNTAIN SYSTEM IN BRITISH COLUMBIA AND ALASKA*

BY ARTHUR C. SPENCER

(*Presented before the Society July 1, 1902*)

CONTENTS

INTRODUCTION

The Pacific mountains of the United States, as defined by Powell,† occupy a belt between the Pacific ocean and that region of lower relief which, lying west of the Rocky mountains, comprises the Basin ranges on the south and the Columbia plateau on the north. Had the discussion presented by Powell been extended to the physiographic features of the whole of the North American continent, it would doubtless have been recognized that the Pacific mountains are continued toward the south into Lower California and toward the north, northwest, and west through British Columbia, the mainland of Alaska, and the Aleutian islands. The colligation of the features of high physiographic relief throughout this belt under the designation of the Pacific Mountain system is here proposed at the suggestion of Mr Alfred H. Brooks.

Throughout its extent, the Pacific system has a general parallelism with the Rocky Mountain system, but between the two in all latitudes

* Published with the permission of the Director of the U. S. Geological Survey.

† Physiographic regions of the United States. Geographic Monograph, New York, 1896. Pp. 65–100.

there is a wide belt of relative depression, marked in the extreme south by the gulf of California; within the United States by the faulted plateaus of the Basin ranges, and the Columbia plateau; in British Columbia by the Interior plateau, and in Yukon territory and Alaska by the Yukon plateau.

The portion of the Pacific Mountain system with which the present paper is concerned lies between the northern boundary of the United States and the mainland coast of Alaska in the vicinity of the Alaskan peninsula. The generalizations which have been attempted are the direct outgrowth of the principal conclusions concerning the physiography of the Copper River district, already presented by Mr F. C. Schrader and the writer in a report on that region.* The field-work of the writer in Alaska has not extended beyond the drainage basin of the Copper river; but from the recorded observations of geologists who have visited other portions of the coastal mountains, and from conversations with some of them, he has been led to remark the similarity of certain physiographic features throughout the whole of the region outlined, and to seek certain correlations. In bringing together the available facts, he has been surprised to find so much alignment of evidence in the direction of a few wide-reaching conclusions regarding the topographic development of the region at large.

There are two notable resemblances between the physiographic features of the Copper River region and the other portions of the coastal belt: In the first place, the existing descriptions of the Coast range, both in British Columbia and Alaska, suggest that their summits represent the denuded remnants of former peneplains; secondly, the Copper river, as well as the large rivers which rise in the interior and flow across the Coast range, are antecedent to the existence of the present mountain ranges. It is the object of this communication to state the relations which are indicated by a consideration of these two features of physiography. The present statement of the conclusions which have been reached is necessarily tentative and their discussion incomplete because of the fragmentary nature of the recorded evidence; but it is hoped that the suggestions which are made will prove of value to observers who may have future opportunity to extend existing knowledge regarding the physiography of the Northern Pacific province.

General Description

Beyond the state of Washington the component ranges of the Pacific

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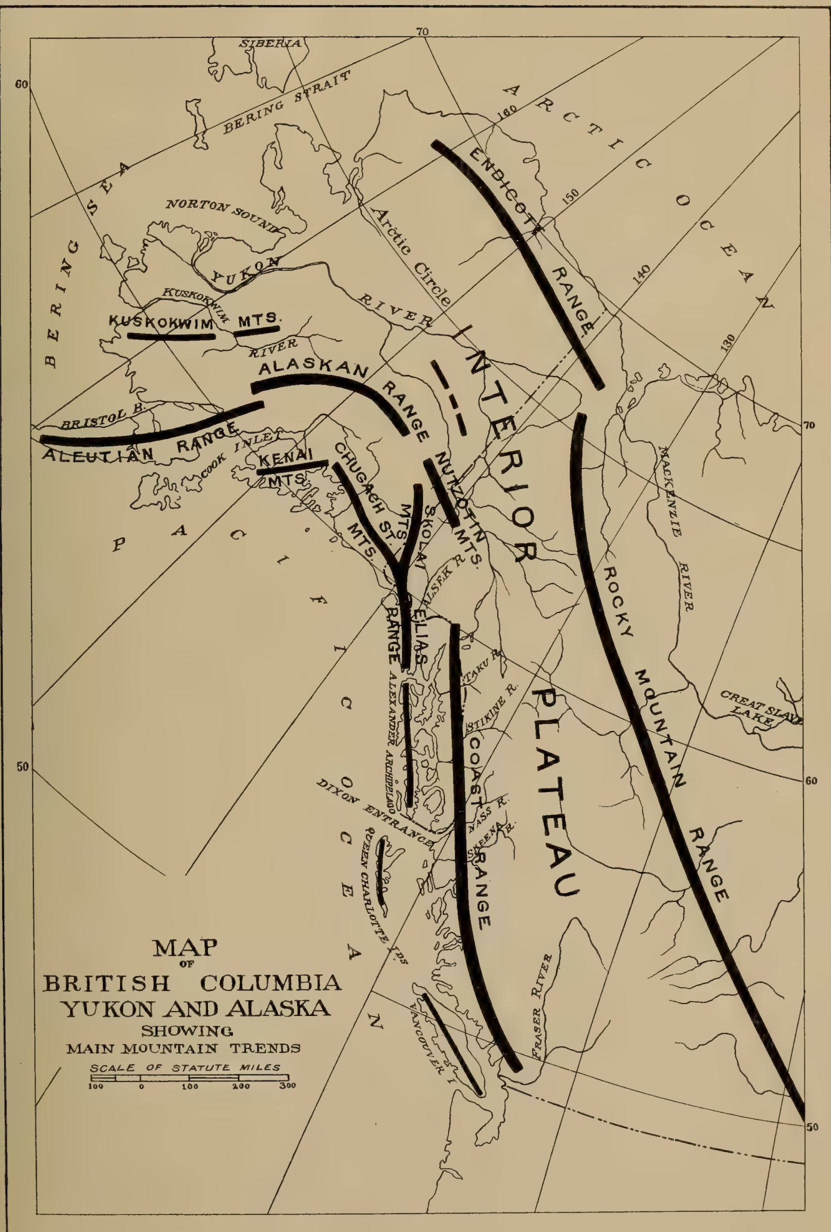
* Department of the Interior, U. S. Geological Survey, Charles D. Walcott, Director, Washington, D. C., 1901, pp. 1–94.

See also "A Reconnaissance of a Part of Prince William Sound and the Copper River District, Alaska," in 1898, by F. C. Schrader. Twentieth Annual Report, U. S. Geol. Survey, part vii, 1900.



MAIN MOUNTAIN TRENDS OF BRITISH COLUMBIA, YUKON, AND ALASKA

mountain system sweep northwestward as far as mount Saint Elias, near the coast, and mount Kimball, about 200 miles distant from the open waters of the Pacific ocean. In the vicinity of these high mountains the axes both of the coastal and the inland ranges take a more westerly course and, continuing with a general parallelism, turn gradually to the southwest, until they are cut off by the sea in the Kenai and the Alaskan peninsulas. Toward the southwest a similar trend is continued beyond the mainland by the volcanic Aleutian islands. This belt, with a mainland extension of nearly 2,000 miles and a width of from 50 to 250 miles, comprises the principal ranges of the system, disposed in a crescent-like curve concentric with the continuation of the Rocky Mountain axis across the British possessions and northern Alaska, and also with that portion of the Pacific coast whose configuration is determined by their existence. The elongated drainage basin of the Yukon river also conforms to the contiguous central portion of this great crescent.

The representatives of the Pacific system from southern British Columbia to Icy strait and Cross sound, Alaska, are the outlying island chain which has been called the Vancouver range and the mainland or Coast range.*

Beyond the Alexander archipelago the southeastern end of the Saint Elias range, rising from Cross sound to Icy strait, divided by Glacier bay into two portions. The inner of these, which has been called the Chilcat mountains, is overlapped on the landward side by the Coast range, which in this region merges with the plateau of the interior. As it continues toward the northwest, the Saint Elias range has an average width of not less than 150 miles, but beyond its culminating peaks this great upland belt is divided by the eastern drainage of the Copper river. On the seaward side the coastal mountains connected with the Saint Elias range swing into a westerly trend, and are continued as the Chugach range across the lower course of the Copper river and still toward the west, until they join the mountains of the Kenai peninsula, lying between Prince William sound and Cook inlet.

The inland continuation of the Saint Elias range maintains a northwesterly trend through the Skolai mountains to the vicinity of mount Wrangell. To the northeast of this volcano lies the Nutzotin range, which likewise has a southeast and northwest trend, but which overlaps the true continuation of the corresponding Saint Elias axis.

The Mentasta mountains, which are the continuation of the Nutzotin range, are overlapped on the northwest by the Alaskan range, which runs in a northwesterly direction as far as mount Kimball. Here its

*In the following discussion the writer will refer thus to these mountains, instead of following Doctor Dawson in designating them as the "Coast ranges."

axis assumes a westerly trend, which is continued as far as mount McKinley, the highest mountain of North America, where it turns again, and the range assumes a southwesterly course, gradually diminishing in height toward the Tordrillo mountains, lying northwest of Cook inlet. Between the Tordrillo and the Kenai mountains and overlapping them lies the Alaskan peninsula, the axis of which is parallel to the course of the mountains on either side. Projected across the Pacific ocean, this axis would follow the trend of the Aleutian islands.

The region lying between the Alaskan peninsula and the lower valley of the Yukon river contains several more or less distinct ranges of mountains, which must be assigned to the Pacific system, but the relations of these to the adjacent Alaskan range are at present only vaguely known.

Copper River District

The Chugach and Wrangell mountains are drained principally by the tributaries of the Copper river. The former as a range is made up of mountains which have been carved by the numerous streams of the region from a portion of the earth's crust which formerly existed as a high plateau. The Wrangell mountains have originated essentially through the upbuilding of volcanic materials on a surface which is the extension of the Chugach plateau. Volcanic activity has been continuous in this group from the time of its inception, probably in the Miocene, down to the most recent time.

The Chugach plateau is considered to have originated in the uplift of a baseleveled land surface, and from the fact that this feature of erosion has been found to bevel the edges of folded and upturned lower Cretaceous strata, its age is considered to be late Mesozoic or Tertiary. It is, however, impossible to fix the date more closely than between these limits. At the close of this long-continued erosion period the whole region had been so completely reduced that all topographic evidences of any dynamic revolutions of Mesozoic date were completely effaced. There could have been no elevations worthy of the name of mountains; no greater eminences than low hills existed to break the monotony of the extensive rolling plains. The upraising of the region was accomplished in several stages, but the intervening pauses were of very short duration when compared with the earlier period of baseleveling.

Two paragraphs adapted from the report upon the Copper River district by Schrader and Spencer will indicate the character of the physiography of the Chugach mountains.*

* Loc. cit., pp. 63 and 65.

LEVEL SKY-LINE OF THE CHUGACH PLATEAU

As viewed from foothills of mount Blackburn, looking across the valley of Chitina river toward the southeast

"The Chugach mountains occupy a coastal belt connected with the mountains of the Saint Elias range toward the east and with Kenai peninsula toward the west. The width of this belt is about 60 miles, and the mountain summits reach an elevation varying between 5,000 and 7,000 feet, though usually grouped about the elevation of 6,000 feet, while above this occasional peaks rise to perhaps 8,000 feet. To one who crosses the range by way of the valleys and low passes, this general uniformity of level is not apparent; but from any considerable elevation within the region the impression is strikingly presented that the summits of the Chugach mountains represent the surface of an ancient plateau from which the mountain masses have been carved.

"The plateau character is well seen from the foothills of mount Blackburn (in the Wrangell group). The level crest line is a very striking feature to the eye, for at a distance of 25 or 30 miles the details of the dissection which the plateau has suffered since its uplift are lost, and only the upland is noted. On a clear day the snow-covered peaks in the vicinity of mount Saint Elias may be plainly distinguished, rising high above the general level of the plateau."

The tributaries of the Copper river, ramifying over an area of approximately 25,000 square miles, take practically all of the drainage of the Chugach and Wrangell mountains. This extensive drainage system is believed to have been developed during the erosion of the Chugach peneplain, and to have persisted with all of its major characteristics, by means of the active downcutting of stream channels continued pace by pace with regional uplift.

Peneplains in the Pacific Mountains

The existing descriptions of the coastal mountains southeastward from the Copper River region are few, but all of them are favorable to the suggestion that the summits of the various ranges are representative of uplifted peneplains.

The only description we have of the southern portion of the Saint Elias range is that of J. B. Tyrrell, but the partial quotation given is sufficient to show the similarity of the physiography of this region with that of the Chugach mountains.

"From Farrow mountain southwest of Aishihik lake the Chilcat range presents the appearance of a vast white plain with the higher peaks rising above. It is a vast plateau lying close to the Pacific coast. Farther north the mountains are more rounded and graded. As a rule they rise 3,000 to 4,000 feet above the bottoms of the intervening valleys.

"Standing on one of the summits, a great number of similar mountains may be seen on every side, all about the same height and probably cut out of the same extensive pre-Tertiary peneplain." *

* J. B. Tyrrell: Bull. Geol. Soc. Am., vol. 10, 1899, p. 194.

Dr C. W. Hayes in describing the Coast range says:*

"Throughout its entire extent, but particularly in its northern portion, the Coast range does not possess a distinct crest line, but is a rather narrow belt of dissected plateau. The breadth of the belt is nearly 40 miles, though the eastern margin, where it merges with the interior plateau, is not well defined."

The character of the southern portion of the Coast range, as viewed from the eastern summits of the range, is described by Dr G. M. Dawson in the following words: †

"From an elevated point of view it will be observed that a large number of the mountain masses of the range approximate in height to 8,000 feet, while a few only reach or slightly surpass 9,000 feet; that there are few instances of really dominant summits with lesser subsidiary mountains grouped around them, but that in widely extended views to the south, west, or north the very numerous and closely set sharp summits run together to form a jagged, but in the main nearly level, horizon line."

In each of these descriptions, excepting the last, the authors leave room for the origin of the plateau feature by subaerial erosion of the land, and in the case of the first two this origin is the one assigned. Doctor Dawson, however, specifically excludes the process of baseleveling in the following words:

"The uniformity in height of the culminating points and ridges of the Coast range can have little, if any, connection with the original form and height of the elevated tract of the earth's crust out of which the existing ranges have been carved by a prolonged process of denudation."

This opinion of the distinguished Canadian scientist and the alternative hypothesis which he develops ‡ to replace the theory of baseleveling as an explanation of the features described both seem unwarranted to the present writer, who believes that all of the plateau features which are described in the foregoing paragraphs are representative of former peneplains which have been elevated far above their original position.

Interior and Yukon Plateaus

The Interior and Yukon plateaus have been described by Dawson, Hayes, and Spurr. In British Columbia the relatively depressed belt

* The Yukon District. Jour. School Geography, vol. i, 1897, p. 237. See also Expedition through the Yukon District. National Geographic Magazine, vol. iv, 1892, pp. 128–162.

† Report on the Kamloops map-sheet, British Columbia, Geol. Survey Canada, Ann. Report for 1895, p. 10 B.

‡ The reader who is not familiar with the hypothesis referred to for explaining the existence of summits of uniform elevation in regions of high altitude will be interested to consult the portion of Doctor Dawson's paper which immediately follows the above quotation.

MOUNTAINS SEPARATING DRAINAGE OF COPPER AND YUKON RIVERS

View looking toward the northeast from edge of Chugach plateau, showing foothills of mount Blackburn and valley of Chitina river

which lies between the Coast range and the Rocky mountains has an average width of about 100 miles and a mean elevation of 3,500 feet. The plateau character of its surface is recognized only when it is viewed in a broad way and contrasted with the mountains by which it is bordered. It is cut off from the great lava plain of the Columbia river, on the south, by some moderately high interpolated mountains near the 49th parallel, and on the north it is interrupted near latitude 55° 30′ by the ends of several ranges lying between the greater mountain features on either side. Beyond the northern end of the Interior plateau, the interval between the Rocky mountains and the Coast range appears to be occupied by an irregular mountainous country extending toward the northwest for a distance of 250 miles, where, in the vicinity of the 58th parallel, a plateau is again noted. The elevation near the mountains is about 2,500 feet, but there is a gradual slope toward the northwest in the upper drainage basin of the Yukon river.* The general character of the Yukon plateau is similar to that which the corresponding feature exhibits in British Columbia. The interstream areas rise to a height of from 1,500 to 2,000 feet or more above the beds of the rivers, and it is only when a broad expanse of country comes under the eye that the plateau character is recognized. The average width of the Yukon plateau from the northern front of the Saint Elias range to the bounding mountains on the Yukon river is about 180 miles. The feature extends westward, touching Bering sea at various places, and probably merging with the tundra which quite generally borders the open ocean on the west.

The Interior and Yukon plateaus are generally admitted to be uplifted peneplains.

Correlation of Peneplains

Two lines of evidence lead to the conclusion that the peneplains which have been described in the preceding paragraphs are mutually equivalent. The history of the drainage features throughout the province, which furnishes at once the most acceptable and territorially the most widely applicable basis for this correlation, will be given in the next section after directly comparing the attitudes and relations of peneplains in adjacent physiographic belts.

It is known that in the central and northern portions of the Coast range the plateau-like crest of the mountains has a slope toward the interior of the continent. This relation is to be observed in the vicinity of the Stikine and Taku rivers and in the region adjacent to the White

*George M. Dawson: The later physiographical geology of the Rocky Mountain region in Canada, etcetera. Trans. Roy. Soc. Canada, vol. viii, 1890, sec. iv, p. 5.

and Chilkoot passes, where the summit plateau merges with the plateau of the interior.* Again, as pointed out by Hayes, Tyrrell, and Brooks, the Coast range diminishes in height northwestward from the vicinity of Lynn canal until its flat summit merges with the Yukon plateau. Thus we have observations in two localities tending to show the direct equivalence of the plateau of the interior with that of the Coast range in its northern portion; and since the continuance of both features toward the south is a known fact, it is held that the two are equivalent peneplains throughout the length of the Coast range.

Westward from the region which has just been described, it is believed that the Chilcat peneplain in the southeastern portion of the Saint Elias range corresponds as an erosion feature with the adjacent Yukon plateau, which stands at a considerably lower altitude. The contiguous and overlapping portions of the Coast range and the Chilcat mountains are both known to be dissected plateaus, and while, as has been noted, the summit surface of the first descends toward the northwest and that of the second is known to rise in that direction, the recent topographic work of the United States Geological Survey shows that they have similar elevations in the vicinity of Lynn canal, where they are separated only by Chilcat inlet and the valley of which it is an eastward continuation. On this account it seems more likely that the peneplains of the two ranges are of the same age than that they were produced at different dates. Considering together the two relations which have been mentioned, it may be accepted as most probable that the peneplain shown in the summits of the southern portion of the Saint Elias range is the physiographic equivalent of the Coast Range peneplain and of the Yukon plateau.

The correlation of the Chugach peneplain with the features whose interrelations have been thus far discussed is more difficult because of the great distance intervening between areas which can be directly compared. However, the equivalence of the Chugach and Chilcat peneplains is suggested by their mutual attitudes to the Saint Elias group of mountains. It has already been stated that the general altitude of the plateau summit of the Saint Elias range increases northwestward from the Chilcat mountains toward the culminating peaks of the Saint Elias group. The Chugach plateau also ascends from the vicinity of the Copper river toward the same high summits, which, as viewed from the foothills of mount Blackburn, in the Wrangell group, may be seen to rise high above the general level of the country which surrounds them. As a matter of fact, the region intervening between the Copper river and

*C. W. Hayes: Expedition through the Yukon district, p. 129.

A PORTION OF THE CHUGACH MOUNTAINS

As seen from forks of Chitina river, looking toward the southwest. It illustrates the topography of Copper River basin and the dissection of Chugach plateau

these high mountains is deeply dissected; but from any elevated outlook the even topped summits of the mountains fall into a seemingly unbroken surface, on which the snow-mantled cones of the dominating mountains appear to rest as upon a plain. The practical identity of the peneplain in the two regions is thus strongly implied; but, in addition, it may be noted that the region which lies north of Saint Elias probably likewise exhibits the character of a dissected plateau. The truth of this surmise is indicated in a view looking northward from Saint Elias, which was published as an illustration in the account of the ascent of Saint Elias by Prince Luigi.* The presence of this high plateau suggests that there is an unbroken continuity of the ancient peneplain on three sides of the Saint Elias group of mountains.

The immediate comparison of the Chugach and Yukon plateaus is at first suggestive only of the existing difference in the elevation of their surfaces. Along the northern faces of the Saint Elias, Nutzotin, and Alaskan ranges there are abrupt scarps and steps, amounting to several thousand feet, between the supposed equivalents of the Chugach plateau and the surface of the plateau in the Yukon basin. It seems, as will be shown later, that the two features can be regarded as equivalent only by admitting the existence of delimiting faults of very recent date and of large proportions. The description of the Nutzotin range † does, however, furnish a clue of probable significance in this connection, since it makes it possible to suggest that the Yukon plateau and the summit surface of the Nutzotin range are parts of the same peneplain.

The Nutzotin mountains, which lie north of the Wrangell group, facing the Yukon plateau, are drained by the headwaters of the Tanana river. From the Nabesna river, which is the western of the two main sources of the Tanana, these mountains have a southeasterly course, extending some 250 miles toward the White river, within 20 miles of which the elevation decreases, so that they become a low range of hills. When projected toward the southeast, the trend of the Nutzotin axis coincides with a range lying north of lake Kluane, which probably merges with the Yukon plateau in the vicinity of the Kaskawulsh river, a tributary of the Alsek.

Antecedent Rivers

There are several large rivers which take their rise within the region of the inland plateaus of British Columbia and Alaska and flow in deep trenches across the high barrier of the coastal mountains and debouch

* The ascent of mount Saint Elias, by H. R. H. Prince Luigi Amedeo di Savoia, 1900.
† See Brooks, loc. cit., p. 346.

into the Pacific ocean. The most southern of these streams is the Columbia river, which Russell * has described as antecedent to the uplift of the Cascade range. The Fraser river also, according to the observations of Dawson,† may be considered as having maintained its early course regardless of the upraising of the Coast range across its path.

The origin of the Skeena, Naas, Stikine, and Taku rivers of British Columbia and southeasternmost Alaska has not been discussed hitherto. They are, however, believed by the writer to be surely antecedent streams, for the reason that the peneplain of the Coast range may be identified as continued from the Fraser river northwestward, across each valley in turn, to the vicinity of Lynn canal. Moreover, the directly observable equivalency of the summit and inland plateaus in the Taku region has already been indicated, from which it follows as a strong probability that the Taku river developed on a continuous peneplain sloping toward the sea, and that the Coast range was uplifted across its previously established course. The other rivers named are by analogy regarded as of similar origin.

Passing to a consideration of the Alsek river, it has been described by Brooks ‡ as antecedent to the uplift of the southeastern wing of the Saint Elias range. This river has lost much of the drainage which at one time belonged to it, through northwestward tilting in the region of the upper White river, and probably also because of ice dams which once existed across its course. A wide valley-like depression was traced from the vicinity of Dezadeash lake approximately north of the mouth of Alsek river northeastward to the head of the Tanana river, and evidence tends to show that this valley was once occupied by a great river which drained into the present Alsek. At present the drainage is not conformable with this valley, showing that fundamental readjustments have taken place, but the lower river course is still maintained as a waterway from the interior to the coast.

The headwaters of the Copper river do not penetrate the Yukon plateau as do the other rivers which have been mentioned, but the river drains an extended basin, separated from the interior plateau region by the northwestward continuation of the Saint Elias range and lying back of the Chugach mountains, which form the western coastwise prolonga tion of the Saint Elias range.

A sketch map of the Copper river and its tributaries has been prepared

* "A reconnaissance in central Washington." Bull. U. S. Geol. Survey, no. 108, 1893, p. 97.

† G. M. Dawson: The later physiographical geology of the Rocky Mountain region in Canada, etc. Trans. Roy. Soc. Canada, vol. iii, 1890, p. 17.

‡ Alfred H. Brooks: A reconnaissance from Pyramid Harbor to Eagle City, Alaska, etc. Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 354.

RELATION OF COPPER AND ALSEK RIVERS TO COASTAL MOUNTAINS

to show its general features. From this will be seen the extent to which this stream has monopolized the drainage of a wide region. From the head of its delta to the lower end of its interior basin the length of the river is nearly three times that of any other river between the Alsek and Cook inlet, but beyond this point it has an equal length to its main head, and several of its tributaries are longer than any stream which flows from the Chugach range directly into the sea. Moreover, the divide between its southern tributaries and the streams of the Pacific slope is nearer the coast than to the valley of their master stream. These facts, taken with the rugged character of the topography in the intermontane portions of the Copper River system, tend to show that this river has not gained its mastery of the region by headwater erosion and piracy, but that its features are inherited from a mature system which drained an equal or greater watershed previous to the general elevation of the region. From analogy with the Alsek river as well, it seems that the Copper is antecedent in origin, for the two wings of the Saint Elias range were in all probability raised more or less synchronously, and the history of the drainage features in the two regions is likely to have been the same. On the whole it may be fairly inferred that the Copper river is antecedent to the uplift of the Chugach range.

The intermontane portions of the rivers which traverse the coastal mountains of British Columbia and Alaska lie from 6,000 to 10,000 feet below the level of the plateau-like summits of the mountainous belt, while the valleys of their upper portions are incised from 1,500 to 5,000 feet beneath the surface of the adjacent plateau. The greater depth of the valleys within the mountainous belt is their only point of distinction aside from modifications due to ice-work. In both regions the rugged topography near the streams testifies to the recency of the work of excavation.

The conception of the antecedent character of the rivers whose origin has been discussed above, together with the other that the plateaus both of the interior and coastal belts are uplifted peneplains, suggests at once that the mature drainage systems from which the present rivers have inherited their courses were developed upon the peneplains prior to the regional elevation of the northern Pacific province. Previous to the initiation of this upward movement of the land, the precursors of the present coastward streams flowed upon a surface of low relief, which probably sloped uniformly from the neighborhood of the present locus of the continental divide toward the Pacific ocean, and, extending throughout the region now occupied by the Pacific Mountain system, had counterparts in adjacent plains of a similar character, whose slopes were dependent upon the direction of their respective drainage systems.

This line of reasoning forms the most satisfactory basis for correlating the peneplains of the various regions which have been described.

Origin of the Pacific Mountains

The latest dynamic revolution to the existence of which we have any clue in the region bordering the Pacific ocean northward and westward from the state of Washington is one which seems to have closed the Mesozoic. Concerning this disturbance little evidence is now at hand, and there are no means for determining the degree to which it affected the structure of the region in question.* However, at many places in the Pacific mountains there is abundant evidence of revolutions which followed the deposition of the sedimentary rocks of the earlier Cretaceous and of the Triassic. Wherever observed, the rocks belonging to these periods have been folded to a greater or less degree, and in many cases, especially in the older strata, there has been an excessive amount of disturbance. It is certain that these movements were of an orogenic nature, and each in turn must have impressed a new physiognomy throughout the regions which were affected; but, whatever may have been the respective reliefs resulting from folding and uplift, the events of subsequent periods have caused their complete effacement as controlling elements in topography. The mountains which now exist are not belts of high relief because they were raised during the disturbances which ensued during the middle and later Mesozoic, or because of later adjustments of the earth's crust amounting to geologic revolutions. The evidence which has been given is believed to be sufficient to show that planation of early Tertiary time reduced a very large area in British Columbia, Yukon, and Alaska to the condition of a peneplain; and since the completion of this denudation cycle all important earth movements within the province have been restricted to continental uplifts unaccompanied by tangential compression. While the nature of the later Tertiary and recent uplifts is regarded as epeirogenic rather than orogenic, it is recognized that tectonic mountains have been formed, but their elevation is considered to have been entirely incidental to the broad regional movements which have affected Alaska and the adjacent portions of North America.

The upraising of so vast a tract as the portion of North America here considered to an average height of several thousand feet can hardly be

* Dr G. M. Dawson is authority for the statement that where the Cretaceous rocks occur on the seaward side of the coastal ranges they are found to have participated to a considerable degree in an upturning which affected the older strata as well. On the inner side of Vancouver island some of the Mesozoic rocks are reported to be probably as young as the typical Laramie. Am. Jour. Sci. (3d series), vol. xliii, p. 435.

COPPER RIVER

As seen midway in its course through the Chugach mountains. View looking downstream above Bremner river

conceived to have taken place without local differences in the amount of movement, and it is definitely known that the uplift has not been uniform. The Interior and Yukon plateaus have been raised to a progressively greater height from northwest to southeast, so that a gentle northwesterly tilt exists throughout the extent of these features. Local warping of the land surface has been reported in the Forty-mile region near the Yukon river, where Goodrich* has made a careful study of the origin of certain stream adjustments which he considers as due to the combined effect of a general northwestward tilting and local arching of the surface; in the upper White and Tanana regions by Brooks,† and in the Cooks inlet region by Mendenhall.‡

Such variations as these have not resulted in the production of topographic features which would be of striking prominence to the casual observer, and even the slope of the summit level of the Coast range toward the Interior plateau in the vicinity of the White and Chilkoot passes, and toward the Yukon plateau in the vicinity of Lynn canal, are features which would not ordinarily be noted except by a trained geographer. The relations of the Yukon plateau to the Saint Elias range, however, are more prominently presented to the eye.

> "Approaching the northern base of the Saint Elias range the plateau character is almost wholly lost, giving way to steep and rugged though not lofty mountains separated by rather wide river valleys. There is, however, no merging of the plateau in to the Saint Elias mountains, but south of a well marked limit the whole character of the topography suffers a complete change. Between the southern limit of the interior plateau and the northern base of the Saint Elias mountains is a depression running parallel with the mountain range and having an altitude of about 4,000 feet." "Southward across this depression was seen the abrupt northern face of the Saint Elias mountains, with many sharp and rugged peaks rising to altitudes of 10,000 to 12,000 feet." §

It is suggested for future corroboration or disproval that this abrupt scarp-like face of the Saint Elias range may be due to displacement along a great fault by which the Saint Elias range has been raised *en bloc* not less than 7,000 feet in excess of the adjacent portion of the plateau. Following the two features eastward, it is found, as already noted, that the mountain summits decrease in elevation while the plateau surface gradually rises,

* H. B. Goodrich: "Recent warpings as shown by drainage peculiarities." Report on the geology of the Yukon gold district, by Josiah Edward Spurr. Eighteenth Ann. Rept. U. S. Geol. Survey, pt. iii, 1898, pp. 276–289.

† Alfred H. Brooks: Reconnaissance in the Tanana and White River basins in 1898. Twentieth Ann. Rept. U. S. Geol. Survey, pt. vii, pp. 448 and 453.

‡ W. C. Mendenhall: Reconnaissance from Resurrection bay to the Tanana river, in 1898. Twentieth Ann. Rept. U. S. Geol. Survey, pt. iii, p. 333.

§ C. W. Hayes: An expedition through the Yukon district. Nat. Geog. Mag., vol. iv, 1892, pp. 29–130.

until in the vicinity of Lynn canal it attains an altitude of over 7,000 feet, as represented by the summits in the Coast range, which is also the elevation of the adjacent portion of the Saint Elias range. In this region, then, the supposed displacement is reduced to zero, but toward the southeast the fault may be continued with the downthrow on the opposite or coastward side. In support of this belief is the conception that the Saint Elias range becomes partially submerged in this direction, and to the southeast of Cross sound and Icy strait is represented by the islands of the Alexander archipelago.* †

The localization of differential movement along such a fault line is not unknown in other regions, and a similar hypothesis is held by Russell to account for certain phenomena observed upon the opposite side of the Saint Elias range. ‡

Localized deformation in the form of a flexure along the inland side of the Coast range in British Columbia is strongly suggested by the physiographic relations which have been pointed out, and it is believed that as a working hypothesis this explanation of the existing relations between the Pacific mountains and the plateau of the interior is worthy of careful consideration.

The attitude of the Yukon plateau to the northern face of the Nutzotin range is very similar to the relation which it presents against the Saint Elias scarp, and may be referred to the same hypothetical origin. If the suggested causes for the observed physiography of this region are corroborated by future workers, it may be found that the zone of differential movement marked by the inland side of the Coast range is continued northwestward to coincide with the line of movement which forms the northeastern face of the Nutzotin range; also that the Nutzotin mountains are related to the western continuation of the Saint Elias range as the Coast range is to their southeastern portion. In this case the great break northeast of the Saint Elias range passes between the

* Alfred H. Brooks: A reconnaissance from Pyramid Harbor to Eagle City, Alaska. Twenty-first Ann. Rept. U. S. Geol. Survey, pt. ii, 1900, p. 345.

† The chain of islands which lies off the mainland of British Columbia and southeastern Alaska comprises Vancouver island, the Queen Charlotte group, and the islands of the Alexander archipelago. These islands have been described as constituting a range of partially submerged mountains distinct from the Coast range. From the standpoint of the geographer, this suggestion is not unnatural, since the larger islands lie in the same general trend and are separated from the mainland by a continuous waterway. However, the available data concerning the geology of the islands seem to warrant the belief that the significant features of internal structure in them and in the Coast range adjacent are entirely comparable and of equivalent age, and therefore that the two lines of relief were not formed, as has been supposed, by distinct orogenic movements. It is considered probable that future study of the features of this province is more likely to show that the "inside passage," as a separating depression between the mountains of the mainland and the island heights, has been the result of erosion rather than the effect of crustal adjustments.

‡ I. C. Russell: Expedition to mount Saint Elias. Nat. Geog. Mag., vol. iii, 1892.

Wrangell and Nutzotin mountains. An inspection of the map will make these relations clear to the reader, and open the way to the suggestion that the overlapping of mountain axis, which is general throughout Alaska, may be the direct result of varying degrees of uplift in adjacent portions of parallel belts of the earth's crust, separated one from another by zones of sharp flexure or faulting. Along the axis of any one of these belts the deformation is ordinarily gentle but extensive, while across the belts the breaks are sharply localized.

It is anticipated that the work of the United States Geological Survey now in progress in Alaska will add greatly to existing knowledge of the orography of the northern portions of the Pacific mountains.

Geologic Dates

It is to Dr G. M. Dawson that we are indebted for the earliest recognition of the baselevel character of the Interior plateau of British Columbia, Yukon, and Alaska, and the age relations of the peneplain have been fully discussed by this geologist, who assigns it to erosion continued through Eocene time. In British Columbia the Interior plateau became the seat of a series of fresh water lakes through warping of the surface, which was initiated about the close of the Eocene. In the basins thus formed Miocene sediments were deposited in alternation with beds of fragmental volcanic material and sheets of lava. The descriptions of Dawson refer particularly to the portion of the plateau which extends northward from the United States boundary to where the British possessions join Alaska. Of those by whom it has been noted and described within the territory of Alaska, Spurr* alone has found reason to differ with the date which Dawson has assigned to the feature. This geologist shows that the erosion of the Yukon plateau was contemporaneous with the deposition of the Miocene strata in the lower valley of the Yukon river, and from this argues that the Yukon plateau was eroded in Miocene time. It seems to the writer that the discrepancy between the conclusions of the two authors cited is more apparent than real, for, in the absence of evidence to the contrary, it may be true that the reduction of the peneplain was largely accomplished during the Eocene, even in the region where it has been described as extending into the Miocene. Indeed, a recurrence of planation after the deposition and folding of Miocene strata is recognized by Dawson in British Columbia.

The development of the antecedent river systems and the production of the peneplain were contemporaneous, and the latter therefore date

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*Josiah Edward Spurr: Geology of the Yukon Gold district, Alaska. Eighteenth Ann. Rept. U. S. Geol. Survey, pt. iii, 1898, p. 260.

back to the Eocene. Consequently the present relief has originated since the close of the first great division of the Tertiary period.*

The elevatory movement which has affected the portion of North America here outlined has been differential in the extreme, but the movements have been contemporaneous in different portions of the region. If the conclusions which have been presented are warranted, there need be no question of the relative dates of the different component ranges of the northern part of the Pacific system, since all are of the same date. The fact is recognized, though it has not been discussed because of the complications of the larger problem which it would introduce, that separate uplifts have taken place at different times, with intervening periods of relative stability. There can be little doubt, also, that movements are still in progress, since a portion of the Saint Elias range is known to have been raised in Pleistocene time, as observed by Professor Russell.

Summary

The following propositions embody the principal suggestions which have been presented in the foregoing pages:

I. The interior and Yukon plateaus of British Columbia, Yukon, and Alaska have been previously recognized as uplifted peneplains, and in the Copper River region the summits of the high mountains have been described as upraised baselevel surfaces. It now appears that the uniform summits which are found over the greater portion of the Pacific Mountain system in the north are also representative of elevated peneplains which have suffered deep dissection.

II. The peneplains of the different portions of the coastal mountains and of the inland plateaus can be correlated one with another. The antecedent nature of the rivers which cross the present coastwise barrier demonstrates the identity of the ancient erosion surfaces throughout the region outlined.

III. The Pacific province was raised after the production of the peneplain by erosion extending through Eocene time, mainly through uplifts of a continental character. Regional elevation was accompanied by warping, flexure, or displacement, raising tectonic blocks which have not been effaced by subsequent erosion; but there has been no mountain-building due to tangential compression.

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*Author's note.—While this paper was in the printer's hands I learned the results, soon to be published, of the careful studies of Bailey Willis and George Otis Smith in the Cascade mountains of central Washington. These observations show that the Cascade mountains were formed by direct deformation since baseleveling in Pliocene time—a conclusion which is so closely in accord with my ideas as to the origin of the Pacific mountains that I am led to expect future studies to demonstrate that the beginning of the deformation which I have suggested may eventually be closely correlated with the uplift of the Cascade range. The rugged character of the mountains of the Pacific province would of itself suggest a very recent date for their uplift—a point which might well have been emphasized in my discussion.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 14, PP. 133-152 APRIL 20, 1903

WAS MAN IN AMERICA IN THE GLACIAL PERIOD?

ADDRESS BY THE PRESIDENT, N. H. WINCHELL

(*Read before the Society December 30, 1902*)

CONTENTS

INTRODUCTION

The problem of the existence of man in America before or during the Glacial period has received fresh impetus by recent discoveries in the Missouri valley. The lively interest which these discoveries have aroused has led me to occupy the hour which is customarily allowed to the retiring President of the Society in a consideration of these new facts.

Those who investigate the early history of mankind have been compared * to explorers in search of the source of one of those great streams

* Evans: "Ancient stone implements of Great Britain," p. 425.

that traverse whole continents. Where the river divides, the explorer may take the wrong branch, and at the end of his journey he may rest satisfied with the result of his search. Later explorers, perhaps after the lapse of several decades, may be led to follow up the great branch which was neglected by the pioneer explorer, and, although they soon find reason to correct their predecessor, they fall into a similar error by a similar branching of the stream higher up. The source of the Mississippi was discovered only after it had been announced erroneously several times; so the investigators of the early history of man have driven their research farther and farther up the stream of time. A man's lifetime may be spent in the investigation of one line of research, only to find that he had followed the wrong branch. Another line of pursuit perhaps yields similar results. Even after many years of labor the sum total of the knowledge derived may be summed up as negative results. The future only will reveal whether we are now at a corresponding stage of the search for evidences of Glacial man in America.

Surface of the Country prior to the Glacial Period

In considering the possibility or the probability of the existence of man before or during the Glacial period it will be appropriate to recall, as nearly as present knowledge will permit, the condition of the surface of North America at the advent of the Glacial period.

What were the features of the country before the age of the drift? Were they such as to warrant the suggestion of the existence of man? It must be admitted by all geologists that the advent of Arctic glaciers in temperate latitudes in America was an event unique in geological history, and that it is set off from earlier geological history by a long period of equable if not tropical climate in those same regions. I refer to the Tertiary age, during which the larger part of North America was a land surface on which flourished a remarkable fauna of bizarre mammals. These mammals were prevailingly of large, even mammoth, stature. They probably roamed in forests of Edenic luxuriance or basked on the plains of tropical grassy verdure. Of savannas or swamps there were probably very few, and these were near the ocean or in the vicinity of the mouths of some of the great rivers. The uplands must have been deeply cut by the drainage courses. The waterfalls had receded to the sources of the streams. The rocky substructure stood out conspicuously along the strike of the harder formations, but in general it was buried under a thick stratum of residuum resulting from its own decay. Such residuary stratum is familiar in southern latitudes and

in non-glaciated tracts, and it is known to reach the thickness sometimes of 100 feet, even in areas of crystalline rocks.*

Length of the Tertiary Age

That this pre-Glacial epoch of luxuriant life, which was destined to be rudely terminated, was one of long duration may be inferred from one or two considerations.

First, the great mammals which characterize the Tertiary had no known representatives in the Cretaceous; hence the time of the Tertiary was sufficiently long for their evolution from reptilian or other forms, as well as for their spread and decline. Their extermination seems to have been gradual, some of them having survived even through the Glacial period and almost into the period of human history. As a group, however, the great mammals ceased with the close of the Tertiary. As a fauna the Tertiary land animals constitute at once the most remarkable and the highest form of all the extinct types of life that have dwelt on the globe. The time required for the development of such a dynasty must have been long, its years counting up into the hundreds of thousands or perhaps millions.

A second means of roughly estimating the length of time involved in the Tertiary is by comparison of the erosion effected by streams. It is well known that within post-Glacial time the rivers of North America within the last glaciated latitudes, whether they flow over the drift deposits or over the rocks *in situ*, have done so little eroding that the valleys seem to have been born but yesterday. The marks of the ancient glaciers on the striated surfaces are hardly obliterated, and in northern Minnesota no perceptible erosion of the crystalline rocks can be made out, except where the streams have been aided by local and accidental conditions. The retreat of waterfalls and the production of river gorges since the Glacial epoch are due to favorable stratification.

If we compare this lack of erosion in the drifted latitudes with that which was effected by streams within Tertiary time, we are impressed by the great contrast. In Colorado and in many other portions of the Rocky Mountain region are granites whose origin dates from some point in Tertiary time, and these granites are rotted to gravel and to soil. Streams that flow over them have cut deep gorges and canyons. The weather has wrought them into fantastic pinnacles or mural cliffs whose silent voices tell of their hoary antiquity. Of this decay and erosion but little can be laid at the door of post-Glacial time. The years since the retreat of the ice from Minnesota can be counted in thousands on

* R. Pumpelly: Am. Jour. Sci., vol. xviii, August, 1879.

the fingers of the two hands. What must therefore be the number of years required for the rotting and the canyoning of the Tertiary granites of Colorado? We may safely say they are one hundred times as many as the years of post-Glacial time.

That man was a denizen in North America during this long period or any portion of it there is no affirmative evidence; but that the physical conditions of the continent would not necessarily have excluded him, and, on the other hand, were quite favorable for his habitation, there is reason to believe.

Pre-Glacial Geest Covering

By the term Glacial period is meant the whole time involved in the production of the drift deposits in their present attitudes. It is not necessary to inquire into the relative importance of the periods of warm and cold climates with which the Glacial period was diversified or whether they shall be called phases or epochs. The thickly geest-covered surface suffered a profound erosion. It is but a trite remark to say that the drift deposits are derived from the rocks of the country; but it should also be remembered that to a large extent, and perhaps to a larger extent than is commonly estimated, that derivation was secondary rather than direct. Long exposure had superficially rotted the rocks, as already remarked, to a considerable degree, and this rotted material supplied the first contribution to the drift deposits. It seems but a reasonable inference that this thick geest layer was first disrupted and transported from the northern latitudes, and that in those latitudes in which glaciation waned and finally ceased there was little or none of that disturbance. Between these extremes all degrees of preservation of the geest layer is still to be seen. I do not mean that the geest layer is usually intact within the glaciated latitudes, but that in going toward the south one finds more and more of the direct elements of that rotted material, mingled with the local drift deposits, and less and less of the far-transported material. Finally, the drift deposits cease as transported material, and there is a visible and now well known slow horizontal transition into the loess of the region, in which there is traceable little or no sign of glacial action. If a short consideration be given to the variation and the geographic distribution of the geest, it will be found to display several interesting and important features:

1. The uppermost portions of the stratum, involving a thickness varying from zero to several feet, may be so completely leached that it has the nature of a residuary clay, but below that depth more or less of the alkaline earths remain. Owing to the universality of capillary attraction, by which the deeper ground waters are drawn to the surface wher-

ever evaporation is active, it is perhaps impossible to affirm that the soluble alkaline earths are totally wanting from any notable amount of the residuary clays. If the movement of the surface waters were wholly downward through the residuary layer, it would be inevitable that the soluble elements of the residuary layer should be carried away from the immediate surface, but it is a well known law that surface waters move in various directions after they enter the ground, and that they rise as well as fall.

2. Below that thickness of the geest in which the most complete decay has taken place, and from which there may have been abstracted the soluble elements, there is a stratum but partially decayed and but little leached. In this zone the alkaline elements from above may have become concentrated, so that on analysis the percentage of soluble elements may be greater than in the original rock. In the midst of this less decayed zone are numerous or rare pieces of the original rock of the country, more or less surrounded by a coating that has resulted from the immediate alteration of the pebbles themselves, and in other cases such residua of the solid rock can be seen to have become almost wholly converted into geest, their outlines only remaining to denote their former presence and their size.

3. Finally, at the rock surface is the lowest part of the geest. Here are mingled undecayed masses of the country rock along with more or less wholly decayed rock matter, and in some instances the rock itself is deeply altered, so that there is a slow transition from the decayed rock to the undecayed. Here are found boulders of decomposition, usually not angular.

This layer of rotted and semi-rotted rock, which sometimes reaches a thickness of more than a hundred feet, has been the prey of the weather during the long period of its formation. It has been subject not only to the rains and the frosts, but also to the drouths and the winds, and if eolian forces can produce loess, it must have been extensively formed during this long period of pre-Glacial exposure. The same layer now mantles the rock surface in southern latitudes. Independent of aqueous agencies these southern countries should be the most noted for typical and extensive deposits of loess.

If we consider for a moment the geographic distribution of the different formations that furnished the geest, some interesting inferences at once become apparent. Certain characteristics of the geest are geographically coincident with certain formations. It would hardly be questioned by any geologist that the softer and younger rocks decay more rapidly than the older. Hence the Tertiary and the Cretaceous would disintegrate and rot more rapidly than the Carboniferous and the Car-

boniferous more rapidly than the Archean. We observe here that these softer rocks occupy large areas in that part of the interior of the continent where the superficial decay has been greatest. Large amounts of this have been carried to the gulf of Mexico by the Missouri, the Mississippi, and their tributaries, but the western country, especially in the region of the plains, is still covered with a thick sheet of this residuum. This sheet becomes thinner toward the north or toward any of the crystalline rocks. It was not only thinner toward the outset in areas of the harder rocks, but has been reduced by glaciation and the powerful drainage and erosion engendered by it.

Advent of the Ice-sheets

With a covering of this kind, which may be said to have been universal over the land areas, the ice invasions came over the northern portion of the United States. It was at first supposed that the Ice age was marked by a single invasion. About 1870 it was discovered in Ohio that there were two, and that they were separated by an epoch of temperate climate sufficiently long to produce a thick soil and a forest growth. This has been recognized very generally in America, and it has been discovered farther that other fluctuations of the ice-sheet were equally marked and other interglacial epochs, marked by similar proofs of mild climate and forest growths, have been detected from time to time. According to the latest statement of Professor S. Calvin, the State Geologist of Iowa, where by far the greater part of the deciphering of the history of the Pleistocene has been done, there were five ice epochs separated by four interglacial epochs. These have been detected and more or less defined in the state of Iowa, namely:

First glacial stage: pre-Kansan, or sub-Aftonian.
    First interglacial stage: Aftonian.
Second glacial stage: Kansan.
    Second interglacial stage: Yarmouth. In Iowa, Buchanan.
Third glacial stage: Illinoian. In Iowa, Buchanan.
    Third interglacial stage: Sangamon. In Iowa, Buchanan.
Fourth glacial stage: Iowan, which formed the main loess deposit.
    Fourth interglacial stage: Peorian.
Fifth glacial stage: Wisconsin.

The Wisconsin drift, which is that which prevails in Wisconsin and Minnesota and is supposed to be that which covers New England, is marked by the great moraines which have been traced across the United States. Professor Calvin says it is

"very much younger than the Kansan or the pre-Kansan. There is an enormous interval between the earliest and the latest of the ice invasions. The earlier gla-

cial and interglacial stages seem to have been longer than those of later date. Some of the interglacial intervals were many times as long as the period which has elapsed since the disappearance from Iowa of the great ice fields which characterized the Wisconsin stage of glaciation. If the time since the Wisconsin is taken as unity, the time since the Kansas is at least twenty. The history of glaciation in Iowa is long; the records are exceeding complex."

If the time elapsed since the Wisconsin be 8,000 years, as is now generally accepted by glacialists, the time since the Kansan, according to the ratio given by Calvin, is 160,000 years. If allowance be made for the Aftonian interglacial epoch and for the pre-Kansan glacial epoch, I think it would be entirely safe to say that the first ice invasion inaugurating Pleistocene time in America advanced upon the temperate latitudes at least two hundred thousand years ago.

The Loess

THE HYPOTHESES AS TO ORIGIN

It may readily be seen that from such a long and complex glacial history there must have resulted a complex product. There were advance stages as well as stages of retreat, and the drainage waters of the stages of advance were long continued, and probably as long continued as the drainage waters of the stages of retreat. Each glacial stage disrupted and rewrought within the zone of its activity the deposits of all earlier stages, or buried them under its own drift sheet. It is by the study of these successive phases of the drift of the country, and by a collocation of the phenomena with the geographic distribution and with latitude, that the records of the Pleistocene are slowly being interpreted into known terms of science. Of all these phenomena, I will call your attention specifically to but one, namely, the loess of the great valleys of the interior. What was the manner of its formation and accumulation?

The loess was first recognized in this country by Sir Charles Lyell, on the lower Mississippi. By him it was considered an aqueous deposit due to a flooded stage of the Mississippi river. It has been traced from the lower Mississippi throughout the whole of its extent south of the Iowan drift, over nearly the whole of the valley of the Missouri, and up several of the other great tributaries both from the west and from the east. Although it varies somewhat in composition from place to place and exhibits some peculiarities of topographic distribution, it has not been found to be separable, so far as the latest surface deposit is concerned, into different parts as to date or mode of origin. The opinion of Lyell as to its mode of origin was unanimously accepted by geolo-

gists until the hypothesis of Richthofen, which assigns an eolic origin to the loess of China, accepted, as it was, and reinforced by Professor R. Pumpelly. At the present time a few geologists accept the eolian theory, and almost wholly explain the phenomena of the loess by that theory. A few others admit a modified and subsidiary agency due to wind cooperating with water and somewhat changing the original mass, while a considerable number, who are those not directly concerned and who constitute probably the larger half of the geologists of the United States, do not have positive convictions, but prefer to maintain a receptive attitude while waiting for the demonstration of either the eolian or the aqueous hypothesis. The discussion is becoming acute. Some of the principles and the facts that are put forward are so plainly stated that it is possible to consider them without danger of misconception.

The aqueous hypothesis requires the following:

1. That the whole mass be water-deposited.

2. That it shall have once filled the valleys of the streams whose bluffs it forms nearly or quite to the tops of those bluffs, the present immediate river valleys having been excavated in the loess since its deposition through the erosive and transporting action of the rivers themselves.

3. That the main body of the loess is contemporary with an ice epoch, now known to be the Iowan stage of glaciation.

4. That the loess-forming conditions required a low-lying attitude of the regions where it was formed, resulting in slow drainage, enlarged rivers, many lakes, vast swamps, and mud flats.

5. To this should be added, as a later proved corollary of the aqueous hypothesis, that the loess is not everywhere the same, either in composition or in structure, but depends on local conditions, and that it passes both horizontally and vertically into glacier-laid deposits.

The eolian hypothesis requires the following:

1. That the loess was transported by winds and deposited where it is found.

2. That it originated in the western plains, or on the dried bottom lands of the great rivers, and by the prevailing western winds was carried into the valleys, or more especially onto the immediate bluffs of the main rivers.

3. That the valleys were never filled with it, but, on the contrary, the resultant effect of the winds has been to keep it out of the immediate valleys through the powerful action of high winds in raising dust storms along the dried flood plains.

4. The structure of the loess, as well as its fossils, indicate only land agencies.

AQUEOUS ORIGIN OF THE LOESS

Without attempting here to show the weakness of the eolian hypothesis, I will mention some of the facts which appear to sustain the aqueous. The first and most significant fact bearing on the origin of the loess consists in this, that there have been two thorough investigations and discussions of the loess by competent geologists, who spent much time and labor on its distribution, mode of transportation, and its origin and relative date. I refer to that of Chamberlin and Salisbury and to that of W J McGee. These long continued and able researches resulted in the adoption of the aqueous theory. The report of Chamberlin and Salisbury is published in the Sixth Annual Report of the United States Geological Survey, and the report of McGee in the Eleventh Annual Report of the same survey. These reports, which for thorough, impartial, and patient research, will long remain classics of American glacial geology, can not lightly be set aside.*

In the second place, it is found that the loess is a direct and contemporary variation or derivative from till. It was in 1877 that the writer made the first recorded observation and publication to that effect. In making the survey of Rock and Pipestone counties, in the extreme southwestern corner of the state of Minnesota, this most important fact was discovered.

"The northern part of Pipestone county lies not far from the coteau des prairies, which is a vast glacial moraine. In traveling southward there is a gradual superficial change in all its characters. This change pervades at first but a small thickness of the deposit, but by degrees involves the drift to the depth of 20 feet. At first there is a diminution in the number of visible boulders; then a smoothness in the creek bluffs; then a gravelly clay on the surface, fine and close; then a closeness in the prairie soil; then in digging wells a few limy concretions are seen mingled with small gravel stones, and at last a fine crumbling loam clay which cannot be distinguished from the loess-loam, which extends to Sioux City in Iowa, and there is known as the loess-loam of the Missouri valley. Wells dug in the southwestern part of Rock county demonstrate also a *perpendicular transition* from loam to drift clay. . . .

"The writer had abundant and favorable opportunity for observing this change in the grades and cuts of the new railroad from Luverne to the state line, and verified it in wells dug and being dug in that part of the county. In some places the

*Professor Chamberlin has more recently modified his views by suggesting what he has designated a "fluvio-eolian" hypothesis, supposing that wind modified and distributed over higher lands the alluvial loess first formed, the whole having been derived by wash from glacial drift; while the loess of China has been found by Professor G. F. Wright to have been originally aqueous, and afterward considerably redistributed by wind. Journ. Geol., vol. v, Nov.-Dec., 1897, pp. 795-802; Bull. Geol. Soc. Am., vol. 13, 1902, pp. 127-138.

loam passes below into a quicksand. We have here, then, a series of changes by which the loess-loam is produced from the drift hard-pan (or till) by the slow withdrawal of the stones and gravel and the gradual predominance of water action over ice action." *

Since the initial observation the same transition has been observed repeatedly in Iowa by McGee, and by him such transition is made a fundamental fact in an elaborate discussion of the drift of northeastern Iowa; and the later Iowa survey has not called it in question, but, on the contrary, has added much to the details of this relationship. If such transition be a fact, it is impossible to find any place for the agency of wind in bringing it about; but the presence and action of water are everywhere evident in the structure of the deposit as it merges from till to loess.

Following is one of the many statements of Mr McGee affirming this relation between the till and the loess:

"The southern loess of northeastern Iowa generally grades imperceptibly into unmodified glacial drift. So the southern loess is a connecting link not only between divergent phases of the deposit, but between the deposit itself and one commonly regarded as distinct in genesis and in period of formation. It is a hybrid; there is no place for it in the accepted taxonomies; and no name commonly accepted can be applied to it that is not a misnomer with respect to certain of its parts. For convenience it may be styled loess-drift or drift-loess, according to the local predominance of the respective characteristics of two generally distinct deposits.

"The passage from loess to drift in the southern counties is commonly gradual, and the transition in the different diagnostic features of the two deposits is seldom coincident, so that the zone of intermediate character, or passage bed, may be many feet in thickness. Usually the fine comminution and homogeneity characteristic of the loess fail first, and an exceptional number of sand grains, at first fine, but of increasing coarseness, and finally pebbles (sometimes polished and striated) appear; next, the fossils diminish in number, and finally fail; with the diminution of fossils the clay element becomes predominant, and at about the same horizon the obscure horizontal banding fails in turn, and the characteristic promiscuity of the glacial drift ensues; then the calcareous tubules disappear, and are sometimes replaced by films of carbonate of lime coating pebbles and accumulated in cleavage planes; at length the loess-kindchen lose their characteristic nodular form and cavernous structure, and either disappear or become transformed into plates and irregular masses of carbonate of lime accumulated in pockets or about pebbles and boulders; and finally the limy segregations fail. These successive changes supervene in such manner that the fossils sometimes extend into the horizon of striated pebbles; the obscure banding of the upper part of the deposit may reappear well within the promiscuous mass of the drift; the tubules and pebbles are frequently associated, and the horizon of loess-kindchen commonly overlaps far upon that of pebbles and boulders, indeed in nearly every deep roadside gully in southwestern

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*Sixth Annual Report Minnesota, p. 105.

counties (*i. e.*, in central Iowa) and only less commonly in Cedar, Muscatine, and Scott counties, loess-kindchen and pebbles (sometimes striated) may be seen intermingled if not united."

McGee also observed, and fully described, a geographic transition from the drift to the loess. This zone of transition may be many miles in width, and it skirts along the southern boundary of the Iowan drift-sheet. Professor J. E. Todd has described a similar transition in South Dakota.* Further details are unnecessary. It is designed at this point only to call attention to the fact that water only can be said to have supplemented and followed, or to have coöperated with, ice in the production of such a joint product.

STRATIFICATION OF THE LOESS

In the next place, after careful inspection of the loess at Council Bluffs, Iowa, at Leavenworth, Kansas, and at Saint Joseph, Missouri, since the discovery of human remains at Lansing, Kansas, I am satisfied that it shows at all those points either evident horizontal lamination or such remnants of it that it can be safely affirmed that originally it was wholly stratified and water-laid. At Council Bluffs the stratification was seen at the brick yards. The lowest portion seen consists of sand or sandy loess. In the upper portion of the deposit at the brick yards the stratification is less evident, but its presence is plainly indicated by the structures which were subsequently seen more perfect at Saint Joseph. At Leavenworth, at the brick yards, a mass of the loess has slid bodily down a sloping rock bluff. While the most of this sliding mass has lost its evident laminated structure, yet a coarse, broken stratification is preserved. It is preserved completely along its bottom parts, where a heavy, darker, stratum maintains its form, although the whole mass is inclined at an angle of about 25 degrees from the horizon. This is near the very top of the loess deposit at that place, perhaps 150 feet above the river. Although a photograph was made of this tilted stratification, the structure is not well brought out in the print.† At Saint Joseph, with the cooperation of Miss Luella Owen, several very interesting facts were brought to light. These may be summarized as follows:

There are suggestions of former stratification in the homogeneous bluffs where exposed by cutting of streets, some of the perpendicular walls being 50 or 75 feet high. These consist of—

a. Layered arrangement of the shells with which the loess is sprinkled, indicating a surface on which the shells lived or had been gathered together.

* Bulletin no. 158, U. S. Geological Society, p. 93, 1899.

† Mr J. V. Brower, president of the Quivira Historical Society, made this and other photographs

b. The manner in which the face of the cliffs breaks off on being excavated. All over the face of the cliff, sometimes, but usually scattered along the fresh excavations, the spontaneous breaking down of the loess is by a series of horizontal cleavages, leaving horizontal surfaces. The vertical jointage of the body of the loess has often been mentioned; it may be stated that at Saint Joseph the horizontal planes left by the falling of the columnar masses are also conspicuous about the fresh faces of the bluffs. These horizontal surfaces are sometimes upward-facing and sometimes they overhang, according as the columnar mass had toppled off or fallen vertically downward without toppling. These easy cleavages are all horizontal or dip uniformly parallel to each other, the latter particularly in regions where it is evident that the mass has moved with a sliding, slow motion toward either the river (Missouri) or toward the valley of the creek which passes through the city, and has thereby lost its horizontality. They can be explained, as it appears to me, only on the supposition of an original stratification of the whole fine mass, the breaking being coincident with the stratification because of a weakness of cohesion along the stratification planes.

c. Besides these horizontal planes of supposed stratification there is visible, sometimes, on weathered areas on the face of the same cut, *an indistinct fine lamination* coinciding in direction with the planes above described, which also suggests a bedded sedimentary structure for the whole mass.

Besides these intimations of a laminated structure, on searching more widely *such structure was found perfectly preserved* at several places. Such a lamination extends from a point but few feet above the Missouri river to near the tops of the main bluffs, namely, it can be seen at the corner of Dewey avenue and Main street, on a part of the main hill or spur which separates the river from the creek valley, not much above the grade of the Chicago and Great Western railroad. The bluff rises about 25 feet above the point at which the stratification is evident. The same shells are seen in the loess at this point, and the whole aspect is identical with the loess in the higher cuts. Here the visible laminations are from a sixteenth to a thirty-second part of an inch in thickness, or thinner, perfectly horizontal, and cannot be questioned, the laminations extending several rods along the face of the bluff, facing east. On weathering it stands out, but even on being cut off by the knife or spade it is still evident. In cutting out a small square block from the vertical wall the loess easily separates horizontally along the lamination planes into sheets of varying thickness, and it was with difficulty that a block 6 inches square could be kept together long enough to be photographed. This easy separation along the lamination planes seems to confirm the

suggested lamination in the higher bluffs near the river indicated by the little horizontal planes already mentioned.

This horizontal lamination in the general loess mass at Saint Joseph may also be seen in the higher bluffs, especially at points somewhat retired from the exposed cliffs along the immediate valley. On Farrand street between Fifth and Fourth is a butte-like small hill left by the cutting away of the streets, opposite the county jail, showing conspicuous horizontal stratification. This is about 150 feet above the river and 5 blocks from it. At Horns heights, half a mile from the river, are conspicuous and frequent exposures formed by cutting the street grades. Here the loess is generally plainly stratified to near the top of the deposit, and in some cases is interlaminated with sand and gravel, evidently of foreign origin, some pebbles being as coarse as duck's eggs. It also contains pockets of sand so extensive that it is used for mortar, etcetera. Miss Owen stated that some years ago two masses of red sandstone (red Sioux quartzite) were found in the loess at Saint Joseph, a fact which has been reported at various places in Iowa by Chamberlin and Salisbury and by McGee.

In general, then, it appears that the undifferentiated affinities of the loess are toward the north; its extreme derivaties are toward the south. The resultant direction of all ice movement and of all the great streams along which the loess is found in greatest amount is from north toward the south. This coincidence is significant of the relation of the loess to the southward drainage of the country, and requires that the agency of water shall take a paramount rank in any consideration of its origin.

SIGNIFICANCE OF ITS FAUNA

The general horizontal stratification of the loess, when considered in connection with its preference for the valleys of the great streams and for the higher lands where it grades into the drift, seems to set a quietus on other interpretation of its fauna than can be made to harmonize with an aquatic origin for its structure, origin, and distribution. The fact that terrestrial forms are common in the laminated loess and that aquatic ones are rare must be explained in consonance with a broader and controlling general truth. Terrestrial fossils are not uncommon in marine formations. He would be very bold who should assign the Dakota sandstone formation to other than oceanic waters on the ground that it contains many land plants. Many land forms may exist in an aquatic formation, but the *existence of a single aquatic fossil species in the loess requires the presence of water.* Many have been identified by good authorities. How, then, have the land snails been introduced so abundantly into the loess?

It has already been remarked that the main body of the loess originated contemporaneously with the existence of the Iowan stage of the ice-sheet. If the supposition which has been so frequently set forth by those who have studied the problems of the Pleistocene that the ice-laden continent settled to a level below its present attitude be accepted, it becomes evident at once that all southward flowing streams would begin to fill up their channels, where before they may have been excavating them. They wandered more widely and frequently formed lake-like expansions. The ice itself and the till which it bore along or any pre-existing till which it may have disrupted were more or less buried under the slime which resulted from this checking of the erosive and transporting action of the rivers. In many places the slime and the till were mingled in a promiscuous mass, partly by the lingering activity of the ice and partly by the stagnant drainage. The flood-plains were built above their former levels by constant and annual accretions from the muddy waters. They rose in many places, if not everywhere, to the level of the old valley bluffs. The rivers as such were sometimes converted into widely extended lakes, which dropped the same sediment over the submerged country. What could be more certain than that during this filling of the valleys by the growth of the flood-plain, given sufficient time, the snail fauna of the respective latitudes would creep out, as now, on to the flood-plain, and that its testæ should be buried under the accumulating sediments?

The Lansing Skeleton

THE MATRIX OF THE SKELETON

In thus dwelling on the structure and origin of the loess and on the conditions of its accumulation, I have aimed to clear the way for the rational and intelligent consideration of the main topic, namely, *Was man in America in the Glacial period?* I will call your attention now to the late discovery of human remains at Lansing, Kansas, in the loess deposits of the Missouri valley.

I have examined this locality on two occasions.* The first was on August 9, 1902, when I had the company and the assistance of Professor S. W. Williston, of Chicago; Professor E. Haworth, of Lawrence; Messrs M. C. Long and Sid. Hare, of Kansas City, and Warren Upham, of Saint Paul. The second visit was on October 18, 1902, in company with Mr J. V. Brower, of Saint Paul. On reaching the spot, we found Mr Gerard Fowke and Mr M. C. Long, under direction of Professor W. H. Holmes,

* My visits were made at the invitation of Mr J. V. Brower, president of the Quivira Historical Society, and in cooperation with him.

engaged with several men in making a cross-tunnel from the westward, intended to strike the original tunnel at about 40 feet from its entrance. Professor Holmes has generously granted the use here of all facts developed by the progress of the cross-tunnel at the date of my last visit. This tunnel was an open cut, so far as excavated at that time, and it afforded a much better chance to inspect the loess by the aid of daylight. The accompanying diagram shows a generalization of the facts, so far as they bear on the skeleton and its relations to glacial history. I gathered samples of the deposit for microscopical examination.

There are three parts or phases of the deposit penetrated by the tunnel, each of which may be briefly characterized, namely:

1. The layer or stratum, containing rotting limestone slabs, in which the skeleton lay, immediately overlying the ledge of Carboniferous limerock. This is quite unctuous when wet and very fine grained. Its out-

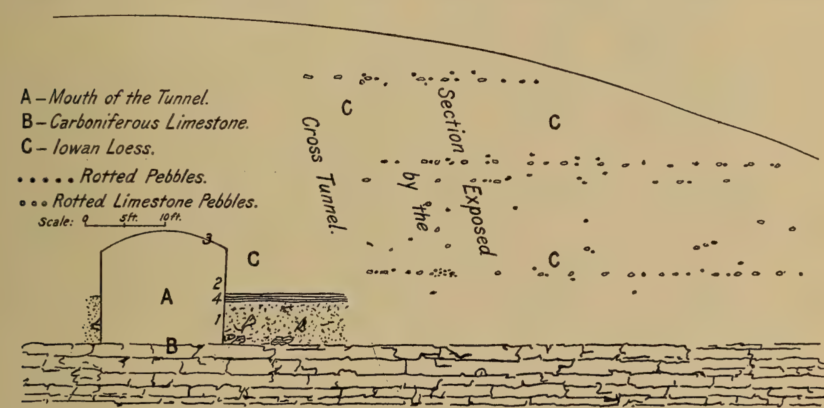

FIGURE 1.—*Section across the Tunnel, parallel with the Cross-cut of Mr Fowke.*

ward color is darker than any part of the tunnel; yet it contains lumps of irregular shape that are lighter colored. It may have been derived largely from the shale that overlies the limestone. It is from one to two feet thick. Its reddish brown color and tenacious texture recall the brown clay that is often mentioned below the true loess. Microscopically this substance is found to contain no quartz, but to consist wholly of very fine scaly particles whose nature can not be exactly determined. It does not afford the least effervescence with hydrochloric acid. The scales appear micaceous or kaolinic, but are usually accompanied by much iron oxide.

2. The grains of the loess above the stratified clay stratum number 4, three and a half feet above the floor of the tunnel, are quite different, being crystalline, consisting largely of quartz, but containing also plagio-

clase, orthoclase, hornblende, and a rare grain of magnetite, and also of microcline, subangular, angular, and a few rounded.

3. A sample from the roof of the tunnel is not noticeably different from the sample just above the stratified clay seam. They both contain ramifying calcareous tubules and effervesce freely.

4. The stratified clay seam which immediately overlies layer number 1 is normally very dense and without effervescence, but since its formation calcareous septaria have formed numerously in it, and in its joints calcareous incrustations have been deposited by ground waters that could not readily penetrate it, so that the stratum is mottled with dark and light. In being excavated it crumbles into many polygonal masses of the size of half an inch and smaller. In the microscopic mounting are seen mostly grains made up of minute granules which are undeterminable, apparently unreduced pebbles of the clay itself, and a few angular polarizing grains of quartz and of plagioclase (?). The clay seam is apparently formed from slow wash from number 1 or from the Carboniferous shale overlying the limestone ledge, or from both, the few crystalline grains and the lime having been derived from the same source as the same in the loess or from the loess itself.

The transition in the character of the deposit from numbers 1 and 4 to numbers 2 and 3 is sudden and remarkable. Certainly the bottom portions of the walls of the tunnel were not derived from the same source nor by the same agency as the upper portions. The bottom portions are not loess. The upper portions, so far as their microscopic characters indicate, are loess.

When we come to consider, however, the megascopic characters of this overlying mass of loess, we see some divergence from the usual loess as seen along the great valleys. It is not finely laminated nor distinctly stratified as a whole. The only sign of the action of water consists in a few rude bands that do not extend the whole length of the excavation.* These bands blend into the main mass, but are characterized by containing limestone pebbles and white spots resulting from the rotting of limestone pebbles. They also contain other pebbles, some of which, being of white quartz, have resisted decay, while others have decayed entirely, leaving only limonitic blotches that show their form and size; but, as already stated, these bands merge into the general loess body, being from 2 to 4 inches in thickness where they show best.

Throughout the loess mass also, where cut by the trench of Mr Fowke, are similar blotches, both white and limonitic, scattered sparsely over the face of the cut. It appears indeed as if the whole loess mass were

*This observation was made in the cross-tunnel of Mr Fowke, west from the original tunnel perhaps 15 feet.

affected by the residua of decay of such materials, the larger only having left definite records of their former presence. This deposit is therefore not a typical loess of the river valleys, although it does not depart from the characters of the loess of the highlands, as in the counties of Rock and Pipestone, Minnesota, and in the paha of Iowa, described by McGee, where the loess grades into till. All its other outward characters comport exactly with the loess of the Missouri valley.

THE SKELETON ITSELF

The human remains, which consist of the skull and many of the principal bones of the body, were found in number 1 of the foregoing description. Besides this a smaller jaw was found at a distance of a few feet from the larger skeleton, indicating a young individual. According to Professor S. W. Williston,

> "the skull does not appear to be much, if any, below the average size. It is distinctly dolichocephalic, the forehead receding, with the orbital margins prominent, and showing especially prominent supraciliary ridges; . . . there is no indication of the ridges above the tubercles on the inner side of the mandible in front, said to be characteristic of *Homo neanderthalensis*; . . . the bones belong to a female between 5 feet 2 inches and 5 feet 4 inches in height. They are unusually small, even for a female; the forearm is unusually long, the pelvis not very broad. The woman was not less than forty years of age."

The skeleton was found 70 feet from the original face of the Missouri River bluff, and beneath 20 feet of loess, in the process of excavation of a root cellar by a farmer named Concannon.

Crucial Questions

EXISTENCE OF MAN DURING IOWAN EPOCH

In the case of the discovery of human relics in the drift deposits, two crucial questions at once arise: Were they found at the place alleged, and what are the nature, origin, and date of the materials in which they occurred?

The fact that these relics were found as represented has been admitted by every geologist who has examined the locality. Not a shadow of doubt has been cast upon the veracity of the farmers Concannon. In my presence, also, other bones were discovered by Mr Fowke.

The nature, origin, and date of the materials which formed the tomb and its covering are the only questions that remain to be investigated. I have already given a description of the nature of the deposit and intimated its origin, namely, a mixed deposit of loess and drift such as

occurs broadly about the margin of the ice-sheet when the ice margin is surrounded, or covered, by abundant waters nearly stagnant, the whole drift, and especially the till-producing portions, being then converted into a semi-mobile mass resembling mud. Such a drift is neither loess nor drift, but a "product of the miscegenation of ice and water," a hybrid which has no name, but whose parentage is well known.

As to the relative date of this deposit at this place, the presumption is that it was the product of the Iowan stage of the Glacial period. It is in the valley of the great river where characteristic and long-known bodies of the loess exist, and near the bottom of that deposit. It shows none but the features of the loess—even the pebbly composition having been noted by Udden * in Pottawattamie county, Iowa, which adjoins the Missouri river on the east. Calvin, reporting on the geology of Page county,† has briefly outlined the method of deposition of the alluvial loess of the Missouri valley during the Iowan stage in these words, which apply exactly to the Lansing locality:

> "While the Iowan ice-sheet did not come within many miles of Page county, it may have invaded the upper part of the Missouri valley, and so have contributed volumes of water loaded with a large amount of fine yellow mud which, following the Missouri and backing into the tributary valleys, produced the effects observed."

It is in this loess sheet that Udden reports, along with numerous species of terrestrial mollusks, two species of Limnea and one of Unio.

This conclusion is that which is arrived at on the face of the facts. It is *a priori* the true one, since it involves the facts and accounts for them in accordance with what is known of the Pleistocene geology of Iowa and Kansas and violates none that are known elsewhere.

ALTERNATIVE HYPOTHESES

If it be desired to further test this, and to suggest outré hypotheses more or less plausible, we may consider the following:

1. That the skeleton was buried by wind deposits, the materials having been brought from the valley of the river by dust storms. It is sufficient to point to the pebbles that are found in the loess, some of them being 3 or 4 inches in diameter and arranged in horizontal bands.

2. That the materials overlying the skeleton were brought to their present position by the joint action of the Missouri river and the small stream which joins the Missouri hard by, during some post-glacial flood stage of the Missouri. This hypothesis will require that since the Wisconsin glacial epoch the Missouri has deposited at this height a sub-

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* Geological Survey of Iowa, vol. 11, p. 260, 1901.

† Op. cit., p. 448.

stance unstratified (in the main) with pebbles that vary in size from that of peas to 4 inches in diameter; but none of the fluvio-glacial terraces that are known to date from the Wisconsin stage, so far as they exist along the Missouri or the Mississippi, are of such materials. They are uniformly fresh, clean, and nicely stratified. Any flood-plain deposits formed later than the Wisconsin ice epoch would necessarily be equally fresh, whereas these are rotted *in situ* and could not have been brought to their present places in the state of decay which they exhibit. They would have been washed entirely clean, and could not now show the layer of decay by which (when not wholly rotted) they are uniformly inclosed.

3. That the material in which the skeleton lay, and that which rises to the surface forming a stratum about 20 feet in thickness, is the result of debris from a higher bluff which once existed at this point but has become degraded by time, this bluff having consisted of Carboniferous strata capped by drift and loess. It is possible to admit such origin for the portions numbers 1 and 4, as already described, with the exception that they must have been formed prior to the deposit of all the overlying loess and not at all contemporary with it. Their composition is wholly different from the overlying loess and they must have been formed without the presence of the loess. It is evident that they can be referred to the Carboniferous shale and limestone and only to them. They constituted a residual clay that antedates the loess and which was a land surface for a long period before the deposition of the loess. This requires that the contour of the Carboniferous was formed before the epoch of the loess, and that no such bluff of Carboniferous rocks (since obliterated) existed at the points supposed when the loess was placed there. Again, granting such may have been the origin of the loess in question, we meet with serious perplexities. First, such a crumbling, accumulating talus slope would not arrange its debris in horizontal layers, but the rolling pebbles would be arranged in layers (if at all in layers) parallel with the slope of the bluff or of the talus. Second, such descending debris once arranged, whether horizontal or oblique, if later than the Wisconsin epoch, would be fresh and unrotted, for there has not been time sufficient since that epoch to effect such decay. If it were done prior to the Wisconsin epoch, it must have been in either the Buchanan or Aftonian interglacial epoch, which would be rather old, but at such epochs the Missouri river flowed, as shown by soundings to the rock bed at Council Bluffs and elsewhere, probably 75 feet below its present surface.

4. That the skeleton may be pre-Kansan, which would require still greater antiquity. In reply to this supposition, it may be pointed out

that it is supposed to be the Kansan drift which exists on the upland on the west side of the Missouri river in this part of Kansas, and that if that be true the loess which might have been formed of this type in the Kansan epoch would (by analogy with the Iowan loess) lie much farther south and could not exist as loess in this part of the Missouri valley. It is, at the same time, true that the Kansan drift-sheet, with its much rotted materials, derived in part from the original geest, contributed very certainly a large quantum to the Iowan drift-sheet, and especially to the Iowan loess, for, according to Calvin, the Kansan drift is altered profoundly in southwestern Iowa to the depth of 40 or 50 feet.

CONCLUSION

There seems to be, therefore, but one conclusion that can be arrived at, namely, that man existed in North America at the time of the Iowan epoch of the ice-sheet; that the bones of the skeleton were buried by the volume of mud and muddy water with which the Missouri valley was filled to overflowing; that the sediments from the muddy mass were augmented by the materials of the Kansan drift, which was spread much earlier over that part of the United States; that they were sometimes not wholly assorted, and that during this flood stage various increments to the mobile mass may have been made from the adjoining cliffs and from the Kansan drift of the immediate vicinity.

COLLATERAL REFLECTIONS

Various collateral circumstances and evidences of the validity of this result might be mentioned, but I will call your attention to but three:

1. First of all should be recorded the fact that for many years instances of the finding of the relics of man in the drift deposits of North America, reported by geologists and non-geologists, accord with this conclusion.

2. The pebbly clays which were deposited in the basins of the Great lakes in subaqueous conditions are apparently the unrotted Wisconsin analogues of the pebbly Iowan loess, and perhaps the gumbo of northern Missouri is the Kansan analogue of an earlier date.

3. The Equus beds which have been reported by Cope and by Williston to contain human remains associated with certain extinct animals have not only a stratigraphic position, but a geographic distribution—that is, they are not known within the area of the Wisconsin glacial moraine. They cannot be distinguished from the loess in which most of the same fossils have been found.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 14, PP. 153-176, PLS. 14-15 APRIL 30, 1903

MARL-LOESS OF THE LOWER WABASH VALLEY*

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(Read before the Society January 2, 1903)

CONTENTS

Introduction

The descriptions and conclusions herewith presented are based on observations made during the course of the geologic mapping of six

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15-minute quadrangles in southern Indiana and Illinois for the U. S. Geological Survey. Most of the evidence was obtained from the Mount Carmel, Princeton, and New Harmony quadrangles, or those crossed by the Wabash river, though a number of minor, yet important features bearing on the loess problem were noted in the Haubstadt, Boonville, and Petersburg quadrangles to the eastward (figure 1). With the exception of the dunes of probable late Winconsin stage, occurring along the border of the Wabash valley, and the recent flood-plain deposits bordering all but the smallest streams, the entire surface of these quadrangles is covered with a mantle of fine silts. Up to the present time no attempts to differentiate these silts have been made, the whole mantle apparently being regarded as a unit and designated as loess.* The detailed field work of the writers, during which all the roads and many of the intervening areas in the region along the Wabash river were covered, brought to light sufficient differences to warrant, it is believed, the differentiation of the surface silts of the region into two distinct physical types. The first of these types includes the thick, yellowish, and highly calcareous silts along the immediate borders of the Wabash valley which are believed to be of aqueous origin. For purposes of discrimination in the following discussion it is designated as *marl-loess.* The second type embraces the more clayey and oxidized silts forming the mantle over portions of the surface more remote from the river, and as a type is known as *common loess.* Although there are no reliable criteria for the subdivision of the latter by its physical or chemical characters, there are several lines of evidence which will be discussed later which seem to indicate that it is not of the same origin throughout, but that its accumulation, though in the main eolian, was in part aqueous. In the following discussion the term common loess is used, as indicated above, to designate a physical type without implied mode of origin. The terms aqueous division and eolian division are used to characterize the subdivisions of the common loess.

Comparison of the Common and Marl-loess Types

COMMON LOESS

Description.—The common loess of southwestern Indiana is an exceptionally fine silt, usually buff or brown in color, which, as a whole, mantles

* See D. D. Owen, in Report of the Geol. Survey of Wisconsin, Iowa, and Minnesota, 1852, p. 132; John Collet, in Report of the Indiana Geol. Survey, vol. 13, pp. 47–48; G. F. Wright, U. S. Geol. Survey, Bull. 58, p. 70; T. C. Chamberlin and R. D. Salisbury, Am. Jour. Sci., 3d series, vol. 41, p. 361; T. C. Chamberlin, Jour. Geol., vol. 5, p. 795, and Frank Leverett, U. S. Geol. Survey, Monograph 38, p. 156. Owen in the Second Report of the Indiana Geol. Survey, 1838, describes an occurence of marl "four miles north of New Harmony," but does not discuss its relations or mode of occurrence.

the hills as a sheet of relatively uniform thickness, having but little influence on the character of the topography. It is essentially non-calcareous, rarely effervescing, and commonly shows on analysis less than 1 per cent of calcium carbonate, though some of the more calcareous portions rise considerably above the amount mentioned.

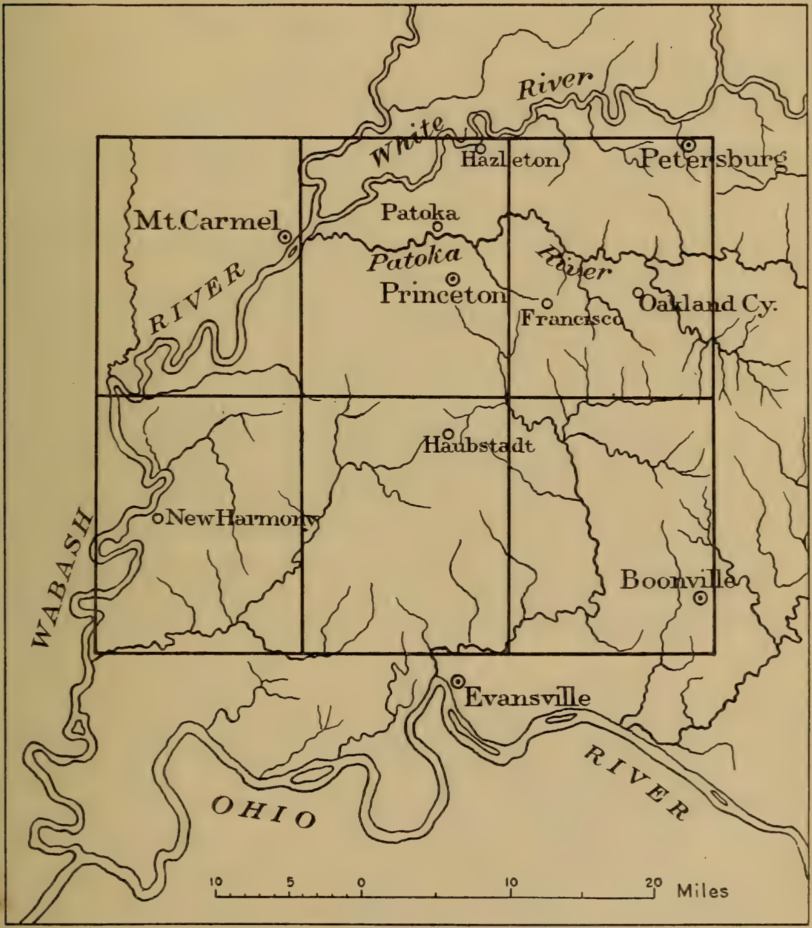


FIGURE 1.—*Sketch Map of southwestern Indiana.*

Showing location of the Mount Carmel, Princeton, Petersburg, New Harmony, Haubstadt, and Boonville quadrangles.

Calcareous concretions are relatively rare, and when found are generally of small size. On the other hand, small iron concretions, both of the tubular and rounded or irregular types, are abundant in places.

The common loess has not been found to carry fossils at any point in the region examined; nor does it contain pebbles except where the sheet is so attenuated that roots penetrate to the till beneath, and on the falling of the tree drag the pebbles upward into the loess. The common loess of the region never presents definite evidences of stratification, though an occasional indistinct banding concentric with the surface and made visible because of differences in moisture absorption capacity of the materials were noted.

Distribution.—Along the borders of the east side of the Wabash valley, loess of the common type is often absent, marl-loess frequently forming the immediate face of the bluffs. This might naturally be attributed to the action of aqueous erosion produced by the impingement of the river during its meanderings subsequent to the deposition of the marl-loess, but its frequent absence from the top for short distances back from the edge of the bluffs calls for some other explanation.

Though differentiated only with some difficulty from the marl-loess, a thin coating of the common type usually appears to begin within a quarter or half a mile of the edge and increases gradually in thickness for several miles, probably reaching a maximum of 15 feet or more at a distance of 6 or 7 miles, beyond which it slowly decreases, until at a distance of 35 or 40 miles it has a thickness of only 2 or 3 feet, or possibly even less. On the west side of the Wabash river the conditions of distribution are similar, though the strip of marl-loess is narrower, and the maximum thickness of the common type occurs much nearer the borders of the valley. The same thinning of the deposit away from the river is noted, the common loess being quite frequently absent, at least in recognizable amounts, at a distance of 15 miles from the Wabash.

The common loess is not confined to any one horizon, but occurs at all elevations from the level of the river bottoms to the crests of the highest hills. Above a certain altitude, which detailed observation has shown to be approximately 500 feet above tide (120 feet above the river), it constitutes the only silt noted. Below this level, especially near the river, the common loess, though generally occurring, is not, as has been seen, necessarily present, the marl-loess which normally underlies it forming the bulk of the silts. Going eastward from the river, there is a persistent, though gradual, decrease in the thickness of the marl-loess, the common type becoming at the same time of greater relative, if not real, importance.

MARL-LOESS

Distribution and range.—The marl-loess occurs on both sides of the Wabash river and upon the surfaces of the rock "islands" which project

above its flood plain. On the west, though occurring at all altitudes up to 500 feet above tide, or 120 feet above the river, it is developed to a thickness probably nowhere exceeding 30 to 40 feet, and except near the immediate borders of the valley, is usually less than 10 feet. It extends back several miles from the river, but, because of its slight development, its precise limits could not well be determined. Good sections of a very silicious form of the marl-loess are to be found in the bluffs at Mount Carmel, while the more calcareous type forms numerous flats standing some 30 or 40 feet above the Wabash plains from mount Carmel southward to Rochester.

East of the Wabash river the marl-loess reaches its greatest development just south of New Harmony, where it forms bluffs rising to the 500-foot level. It does not appear probable, however, that the height of the somewhat receding bluff is indicative of the actual thickness of the marl-loess, for well records on the top give 10 to 25 feet as a common depth to the rock or to the Illinoin till upon which the silts rest, though occasional depths of "marl and blue mud," the latter possibly being a variety of the marl-loess, are reported as high as 50 feet. The marl-loess constitutes the surface formation along the uplands bordering the Wabash flats at many points from New Harmony northeastward to Hazelton and eastward up the White river to Petersburg, reaching frequently to an altitude of 500 feet above tide, but never above. Beyond Petersburg it has not been traced.

The belt-like character of its distribution appears to be controlled by a coincident belt of highlands, of which the inequalities and all but the higher portions have been buried beneath the plateau-like plains of marl-loess.

The superficial continuity of the marl-loess is frequently interrupted by areas of dune sand of a late Wisconsin stage, but as the sand is known in many cases to rest upon the marl-loess, it is extremely probable that the deposit of the latter is essentially continuous within the limit mentioned. It reaches thicknesses of 40 feet or more at Hazelton, and appears to be of a somewhat similar thickness along the bluffs 2 miles northwest of Patoka. The marl-loess also reaches similar altitudes and perhaps equal or greater thicknesses on the numerous "islands" of the Wabash flood plains, among which may be mentioned the Claypole, Gorden, and Mumford hills. In all localities noted the marl-loess is thickest where nearest the Wabash, and gradually decreases until it thins out and disappears, except perhaps for an occasional thin bed, at a distance of 5 to 8 miles from the borders of the river flats. Its eastern limit in the Claypole, Gorden, and Mumford hills has been determined by subsequent meanderings of the Wabash river, which have undoubtedly

removed extensive accumulations which must have existed between the "islands" and the highlands bordering the valley on the east. The eastern borders of the marl-loess deposits east of the Wabash are marked by important drainage lines, probably in part consequent upon the constructional forms resulting from the deposition of the marl-loess.

Color.—In color the marl-loess varies from nearly white through a light gray to a light buff. By far the larger part, however, is characterized by a pale straw or yellowish color, which, with one exception (see page 173), had no counterpart in the eolian loess of the region, and which therefore affords a good general guide to its recognition. The yellowish color, however, is generally found only in the main belt of marl-loess bordering the Wabash valley. In the few remote and apparently outlying deposits which have been recognized the color is usually gray. The gray type is especially impervious to water, in some cases remaining almost wholly unoxidized and unleached even where within 3 or 4 feet from the surface. The yellowish variety, on the other hand, is more porous, and is generally slightly oxidized throughout, although only the upper 2 or 3 feet exhibit the brown and reddish colors which nearly everywhere characterize the common loess. This oxidation of the surface of the marl loess occurs only when the latter is destitute of the coating of loess of the ordinary type. It can usually be distinguished from the ordinary loess, which it strongly resembles, by its deeper reddish brown color and the presence of numerous fine, but rather stiff, clay lumps such as frequently characterize the weathering of argillaceous limestones. Neither the gray nor yellowish types, with the single exception noted on page 173, are ever typically developed above the 500-foot contour.

Composition.—The most conspicuous physical difference between the marl-loess of the yellowish type and the ordinary loess is the greater coarseness of the former. In fact, it might in some instances be termed a fine sand rather than a clayey silt, the individual grains being distinctly visible in several cases. To the unaided eye the grains appear to consist mainly of quartz, though in certain layers finely comminuted shells compose a considerable portion of the material.

In the following table analyses of the common and marl-loess types are given for comparison. Number 1 is a sample of ordinary loess from near Princeton, and was analyzed by Professor Robert Lyons for the Indiana Geological Survey and published in the twentieth and twenty-first annual reports. Number 2 is a sample of marl-loess from the land of B. C. Macey ("4 miles north of New Harmony"), and was given in D. D. Owen's report.* The two are selected because they mark extremes

* "A Geological Reconnaissance of the State of Indiana," pt. 2, 1838, p. 66.

in the range of the $CaCO_3$ constituent. The average sample of the common loess would probably show less than 1 per cent of the $CaCO_3$, while the average sample of the marl-loess would probably show more than 5 per cent.

Analyses of Loess and Marl-loess

Constituent.	Number 1.	Number 2.
SiO_2	71.20	
Al_2O_3	18.56	60.00
Fe_2O_3	1.34	
FeO	.15	.80
CaO	.14	20.27
CO_2	....	15.93
TiO_2	.88	
MgO	.52	1.00
Na_2O	1.26	
K_2O	.32	
H_2O	6.30	2.00
Total	100.67	100.00

Under the microscope, in addition to the quartz and comminuted shell particles, grains of magnetite, mica, etcetera, may also be recognized. In addition to the exceedingly fine sand mentioned, there are sometimes present thin layers of medium or even coarse sand, and in a few instances layers of pebbles were seen. Such layers do not appear to be confined to any particular horizon of the marl-loess, fine pebbles and sand having been found both at the base (southeast ¼ section 9, township 4 south, range 13 west) and at the upper limits (west ½ section 17, township 1 south, range 10 west) of the deposits. The lowest exposures are rather more frequently of the gray clay type than of the coarser yellowish variety, but the gray clays have, however, been noted up to the maximum altitude attained by the marl-loess—(500 feet above tide).

Stratification.—Stratification is manifested by (1) a lamination of the fine silts due to probable variation in composition as brought out by color, (2) by the lamination of the same class of silts due to slight differences in texture, (3) by alternations of clay-like laminæ with sandy layers or of thicker clay layers with sandy beds, (4) by the presence of layers of gravel, (5) by the horizontal linear arrangement of calcareous concretions, and (6) by the similar horizontal character of the fossiliferous bands.

The visible stratification is confined to the yellowish type, though the well records and exposures appear to indicate that the gray type has an approximately horizontal upper surface. The dip of the laminæ when

it could be determined was always under 5 degrees, and it is believed to be an original feature. In direction it appears to coincide, in a general way, either with the trend of the White or with that of the Wabash river. The observed range of the horizontal stratification is from the level of the river flats to the 500-foot contour, a range of about 120 feet. Above this level lines of indistinct banding, and of concretionary layers concentric with the surface of the hills, were noted in several instances, but no traces of a horizontal banding were observed. Figure 1 of plate 14 shows something of the character of the stratification. Several other exposures exhibiting even more conspicuous lamination were seen, but could not be photographed. The following list shows a number of localities at which stratification could be readily observed at the time of the field work in the autumn of 1902:

List of best Exposures of Stratified Marl-loess

1. Kilroy, ½ mile south of (northwest ¼ section 9, township 4 south, range 13 west).
2. Mumford hills (southwest ¼ section 31, township 3 south, range 13 west, and section 36, township 3 south, range 14 west).
3. Poseyville, 4 miles southwest of (northeast ¼ section 1, township 5 south, range 13 west).
4. New Harmony, 1½ miles east of (northeast ¼ section 6, township 5 south, range 13 west).
5. Patoka, 2½ miles north of (southwest ¼ section 12, township 1 south, range 11 west).
6. Hazelton, opposite railroad station.

The best examples of interstratified gravels and sands are found along the road south of Kilroy (section 9, township 4 south, range 13 west). At an exposure on the west side of the road about a mile south of the village there are about 10 feet of sand and gravel overlain by 8 feet of marl-loess, the two being interstratified along the transitional zone. About ¼ of a mile from the town the following section is exposed:

Section near Kilroy

	Feet
Oxidized and leached marl (or loess)	3
Marl-loess	2
Fine sand	6
Marl-loess	10
Sand and gravel at base.	

Fossils.—Fossils were observed in about twenty-five localities in the area surveyed. Their range is coextensive with that of the marl-loess, none being found above the 500-foot level nor beyond the limits of the deposit as described in the paragraph on "Distribution," page 156. They are

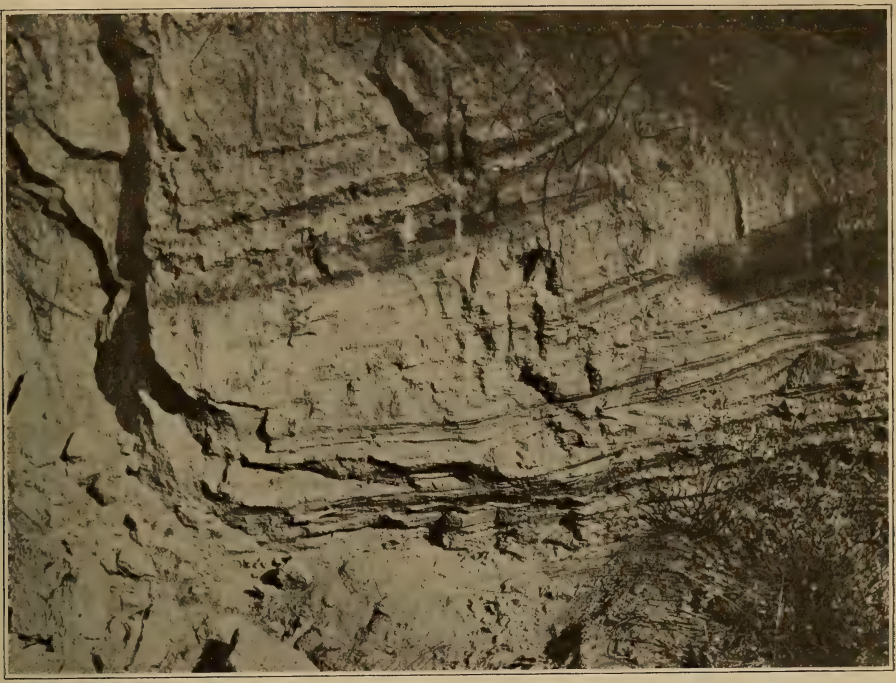


FIGURE 1.—STRATIFICATION IN FOSSILIFEROUS MARL-LOESS

One and a half miles east of New Harmony

FIGURE 2.—STRATIFICATION IN DUNES OF LATE WISCONSIN STAGE, MOUNT CAEMEL, ILLINOIS

STRATIFICATION IN MARL-LOESS AND IN SAND DUNES

doubtless present over nearly, if not quite, the whole of this area, but are usually exposed only in the deeper cuts. The fossils are especially numerous in the gray clay type of the marl-loess, but they are not so uniformly present in the more sandy type, although in places they are very abundant. The following is a list of the more prominent localities at which fossils were noted:

List of Fossil Localities

1. Petersburg, 1½ miles northwest of town, on road to ferry.
2. Hazelton, opposite railroad station.
3. New Harmony, 1½ miles east of (northeast ¼ section 6, township 5 south, range 13 west).
4. New Harmony, ¾ mile south of (west ½ section 1, township 5 south, range 14 west).
5. Kilroy, 1 mile southeast of (southeast ¼ section 9, township 4 south, range 13 west).
6. Stewartsville, ¾ mile southwest of (northeast ¼ section 15, township 4 south, range 13 west).
7. Mounts, 1 mile west of (north ½ section 26, township 3 south, range 12 west).
8. Hazelton, northeast edge of village.
9. Patoka, 2 miles northeast of (west ½ section 17, township 1 south, range 10 west).
10. Mount Carmel, 1 mile southwest of (northeast ¼ section 29, township 1 south, range 12 west).
11. Keensburg, 2¾ miles northeast of (northeast ¼ section 2, township 2 south, range 13 west).
12. Mumford hills (west ½ section 31, township 3 south, range 13 west).
13. Poseyville, 1 mile southwest of (north ½ section 30, township 4 south, range 12 west).
14. New Harmony, 4½ miles southeast of (center section 20, township 5 south, range 13 west).
15. Grafton, 2 miles north of (east ½ section 2, township 6 south, range 14 west).

Collections were made at the first seven of these localities. The species as identified by Dr William H. Dall are as follows:

Locality 1, northwest of Petersburg:

Zonitoides arboreus, Say.
Polygyra monodon, Rack.
Polygyra multilineata, Say.
Succinea lineata, W. G. B.
Succinea humilis, Say.

Locality 2, Hazelton, opposite railroad station:

Zonitoides arboreus, Say.
Patula alternata, Say.
Bifidaria armifera, Say.
Polygyra hirsuta, Say.
Polygyra albolabris, Say.
Succinea lineata, W. G. B.
Helicina occulta, Say.

Locality 3, east of New Harmony:

Conulus fulvus, Drap.
Bifidaria armifera, Say.
Vertigo tridentata, Wolf.
Vallonia cyclophorella, Ancey.
Succinea lineata, W. G. B.
Pomatiopsis lapidaria, Say.

Locality 4, south of New Harmony:

Zonitoides arboreus, Say.
Conulus fulvus, Drap.
Strobilops labyrinthica, Say.
Polygyra hirsuta, Say.
Polygyra monodon, Rack.
Succinea lineata, W. G. B.
Helicina occulta, Say.
Pomatiopsis lapidaria, Say.

Locality 5, southeast of Kilroy:

Selenites concava, Say.
Polygyra thyroides, Say.
Succinea lineata, W. G. B.
Polygyra elevata, Say.

Locality 6, southwest of Stewartsville:

Zonitoides arboreus, Say.
Helicodiscus lineatus, Say.
Conulus fulvus, Drap.
Strobilops labyrinthica, Say.
Polygyra hirsuta, Say.
Polygyra thyroides, Say.
Succinea lineata, W. G. B.
Limnea humilis, Say.

Locality 7, west of Mounts:

Limnea humilis, Say.
Planorbis parvus, Say.
Planorbis bicarinatus, Say.
Valvata tricarinata, Say.
Pisidium variabile, Prime.
Pisidium compressum, Prime.

With the exception of a single specimen of *Limnea humilis*, Say, which was found at the Stewartsville exposure, aquatic or semi-aquatic species were found only at the exposure near Mounts. At this point, notwithstanding there were no observable variations from the type of silt prevailing at the other exposures, all of the species found were aquatic. This difference of the fossil fauna is probably an indication of marked differences in the physical conditions attending the deposition of the silts, the character and significance of which will be discussed on a subsequent page.

Terraces.—Not only do the marl and common loess show marked differences in the composition and structure, but they also exhibit a striking difference in topographic expression. The common loess, as has been stated, occurs in any given locality as a mantle of a moderate and rather uniform thickness, conforming with the inequalities of surface. The marl-loess, on the other hand, occurs in deposits of relatively great thickness, burying all the minor irregularities of the till or rock surfaces and presenting numerous instances of extensive flats or broad, gently sloping terraces.

Figure 1.—Sloping Terrace of the Mumford Hills

Viewed from the south, 6 miles north of New Harmony

Figure 2.—Surface of a Marl-loess Plain

Two and a half miles southeast of New Harmony

PROFILE AND SURFACE OF MARL-LOESS TERRACES

These terraces are exceptionally well developed in the Mumford hills and at a number of points in the region to the east, southeast, and south of New Harmony. Figure 1 of plate 15 shows the appearance of the Mumford Hill terrace as seen from the south. The easterly slope is readily detected. The core of the hills is of rock, which at a few points rises as marl-free " islands " above the general plain of the marl-loess, the remainder being buried, as brought out by the water wells, beneath the mask of marl-loess. Southeast of New Harmony the buried topography is often quite rugged, although, as shown in figure 1, plate 15, which is a reproduction of a view taken in the south half of section 5, township 5 south, range 13 west, about 3 miles southeast of New Harmony, the surface is frequently as flat as a floor. In such regions the variations from the plain are either brought about by the projection of rock "islands" through the marl-loess or by the action of the streams in cutting sharp V-shaped ravines. All the minor drainage has, in fact, been developed since the deposition of the marl-loess, there being few original depressions of importance except those due to thinning along the eastern margin of the deposit. The common range in altitude of the terraces is from 440 feet to 500 feet above tide, very fine examples being noted at the latter altitude in the Mumford hills and south of New Harmony (figure 2, plate 15). The terraces in both cases subside to the eastward to altitudes of 460 or 440 feet, at which levels there are extensive deposits at intervals throughout the area on both sides of the Wabash as far north as Hazelton.

Discussion of Evidence

The maximum development of the marl-loess, occurring as it does along the valleys of the Wabash and White rivers, and its limitation to belts of moderate width on each side of the valleys, appears to indicate that the two rivers were intimately connected with the furnishing of the materials for the deposits.

The range of the marl-loess, as indicated by its typical yellowish color, its stratification, its fossils, and by its terraces, points to a controlling factor which worked within certain fixed limits in the region under discussion, this being a horizontal line or level at an altitude of 500 feet above tide, or approximately 120 feet above the present flood plain of the Wabash.

The fact that, notwithstanding the essentially contemporaneous origin of the common and marl-loess deposits, the former are weathered and leached throughout, while the latter are frequently practically unoxidized and unleached at a depth of 2 or 3 feet, would appear to indicate (1) that the common type is richer in its iron constituent, (2) that the

situation and texture of this type is more favorable to oxidation, or (3) that it was oxidized at the time of its deposition. Analyses show that the first assumption is untrue, and the field examinations of the occurrence of both types, together with comparative studies of the textures, show that the second assumption likewise fails to hold good, the conditions being in fact more favorable to the oxidation of the marl-loess than of the common type. It is thought, therefore, that the differences in oxidation and leaching date back to the period of deposition, the conditions favoring oxidation being pronounced in the case of the common loess and of little importance in the case of the marl-loess. A rapid accumulation in the absence of vegetation, and especially in the presence of water, would afford the simplest explanation of the observed lack of oxidation.

The greater coarseness of the marl-loess may be taken as indicating a more powerful transporting agent than is indicated by the finer material of the common loess. This is especially true of the pebbles which occur up to half an inch or more in diameter, and in positions which preclude a derivation from any nearby drift deposit. Some of the largest and most abundant pebbles were found over the top of a marl-loess flat, at a distance of half a mile or more from the nearest available source, from which the flat on which they were found is separated by a valley which, in part at least, appears to have been determined by an original depression. In the instance in question it seems certain that no agent other than water could have accomplished the observed transportation and distribution of the pebbles. The high calcareous constituent of the marl-loess, as compared with the common loess, indicates, as in the case of oxidation, an accumulation of the former under conditions relatively much less favorable to weathering. An accumulation under water or a very rapid accumulation on the land is thought to afford the best explanation of the observed differences.

The perfection of the stratification, consisting, as it frequently does, of very regular and perfect, though minute, horizontal laminations, is in marked contrast with both the steeply dipping layers characteristic of the accumulations at the front of advancing dunes (lower right-hand portion of figure 2, plate 14), or of the wavy banding characterizing wind-blown materials which have accumulated on dunes covered partly or wholly with vegetation (upper portion of exposure, figure 2, plate 14). It is of a character which in any other substance than a supposed loess would unhesitatingly be referred to an aqueous origin. Its pebbles, as has been noted, occur frequently in situations and of a size which would appear to bar out wind action as an agent in their accumulation. The occurrence of the stratification in repeated instances up

to an elevation of 500 feet above tide, but never above this level, even where the silts are well exposed from their top to the bed rock, would seem to point to water as an important, if not the controlling, factor in the deposition of the stratified beds.

Of the fossils all but those from near Mounts are of land species. This presents at first sight a strong argument that the silts which contain them are of land origin. It was early noted, however, that the fossils are not found in curved layers or pockets as if they had accumulated in depressions of the land surface, but are generally found distributed through the minute laminæ of the silts. The perfection of these laminæ show conclusively that they have never been penetrated either during the period of their accumulation or at any time since by rootlets of any sort, even by the minute rootlets of the grasses. If the fossils are to be considered as being indigenous to the deposit, which is thus assumed to be a land accumulation, we should have the anomalous state of affairs where an abundant fauna, consisting of species which are characteristic of wet wooded situations, was living where there was a complete absence of vegetation, and where consequently there was no food. Such an absence of vegetation could only occur where the climate was either too cold or too dry for vegetation to live, neither of which conditions, it is practically certain, existed in this region during the period of marl-loess accumulation. On the other hand, it seems only natural that land forms should be washed or floated into a body of fluctuating water, and deposited with its sediments, while a general absence of aquatic species may be explained as resulting from a high silt constituent of the waters.

It has sometimes been urged that the preservation of certain of the delicate and fragile forms indicates that water has played no part in the formation of the deposits, it being regarded as too violent in its action. Any one who has seen the relatively heavy shells of some of she smaller littoral shells taken up and whirled along by the winds on our coasts, and who has compared the violence of this action with that of a sluggish silt-depositing stream, will have no doubt as to which is the best calculated to preserve the delicate shells. The presence of the operculum within the opening simply means the shell was buried by succeeding deposits before decay of the animal matter had set it free, and the lack of filling of the whorls, which is exhibited by a relatively small number of the shells, indicates nothing except that in these special instances there was no prolonged rolling or similar movement of the shells by means of which the silt worked its way back into the shell. The fossil shells are not always complete, in fact some laminæ and layers seem to be made up largely of the comminuted fragments of shells. This, however, though sometimes considered as evidence of aqueous origin, could,

as has been pointed out, as well be the result of wind accumulation as of water. The fossils are now found up to the 500-foot level, but never above, a fact which appears to be explainable by the relatively oxidized and leached condition of the silts above this level, the fossils and other lime constituents which the latter must have originally contained having been largely or entirely removed by solution.

To a student of physiography the terraces and silt plains are significant features. In character they are entirely unlike the normal topography of the loess in the Ohio-Wabash basin, and are at variance with any known form of wind accumulation on a similar scale. On the contrary, they are of a form which is typical of aqueous deposition. Their altitude, limited as it is by the 500-foot contour, is again suggestive, if not conclusive evidence of aqueous conditions.

Origin of the Marl-loess

MANNER OF DEPOSITION

The conclusions reached by the writers from the evidences noted in the field, the more important features of which have been presented in the foregoing discussion, is that the marl-loess is an aqueous deposit, consisting of silts deposited in expansions of the White and Wabash rivers.

The upper limit of the marl-loess, as determined by a large number of accordant observations, is 500 feet above sealevel, or approximately 120 feet above the Wabash flat. The terraces are an original constructional feature, whose differing levels and slopes indicate that the deposition did not reach up to anything like a uniform plain of the altitude mentioned. Strictly fluviatile origin is therefore ruled out as an explanation of the marl-loess as a whole, though it is not at all improbable that some of the lower grayish silts are of this origin. No criterion for the differentiation of the strictly fluviatile deposits, if they occur, was found.

The hypothesis which is accepted as best fulfilling the requirements of the evidence postulates a fluvio-lacustrine condition. The valleys of the lower Wabash and Ohio rivers, with their tributaries, are believed to have been occupied by water standing at the level indicated. This body of water seems to have covered large areas in southern Indiana and Illinois and in northern Kentucky, and appears to be recorded throughout the region by marl-loess flats and silted divides at the 500-foot level. Although the waters possessed a lake-like expanse, it is probable that moderate, if not fairly strong, currents existed, and determined the distribution of the loess and the character of its fossil contents.

The fluvio-lacustrine body, like all lakes of its class, was probably

subject to fluctuations of level amounting to many feet. In stages of low water it is supposed that the terrestrial species of mollusks took possession of the shores to the water's edge, and on the ensuing rise are believed to have been floated or washed into the body of water and incorporated in its sediments.

The waters are thought to have been in general surcharged with silt. It is a well known fact that molluscan species rarely inhabit waters highly charged with such material, the Missouri and other rivers of a similar character being nearly destitute of molluscan life in their muddier portions. It is believed that it is to the presence of the high silt constituent, taken in connection, perhaps, with the low temperature of the waters, that the general absence of aquatic species is due.

In the interpretation of the aquatic species found near Mounts (see page 162), several explanations present themselves: (1) The deposit may have accumulated through the settling of wind-transported dust into a local pool subsequent to the disappearance of the general body of water from the region; (2) the deposit may have been formed in the general body of water during a stage when because of deficiency of supply the whole body was relatively free from silt; or (3) the deposit may have accumulated in a bay of the general body of water, in which, from its more or less detached situation, currents circulated with less freedom and were less highly charged with silt. As to the first supposition, it may be said that the topography, the color, texture, and composition, and especially the richness in calcareous constituents, all point to the deposit as being a part of the marl-loess rather than the loess of the common type. The second supposition can hardly be true, as the conditions favoring aquatic life, if at all general, would almost certainly have been marked by aquatic species at some of the other numerous fossil localities. The third supposition, or that assuming deposition in a more or less detached bay, where the waters were clearer than in the main body of water, is believed, on the whole, to be the most satisfactory of the three explanations proposed to account for the occurrence.

DISTRIBUTION OF THE MARL-LOESS

The marl-loess is much more abundant on the east side of the Wabash river than on the west, though the difference is not so conspicuous as might appear at first sight because of the greater abundance of the common loess, with which the marl-loess is likely to be confused, on the same side. Assuming the deposition to have taken place under fluvio-lacustrine conditions, it must be postulated that the main current hugged the western shore. Along the line of this current little deposition would take place, while farther away, where the waters were quieter, the deposition would go on rapidly.

Four possible assumptions as to the cause of the hugging of the west bank by the current suggest themselves: (1) It was entirely accidental; (2) the current followed the laws of deflection due to the earth's rotation; (3) it was governed by a coincident preglacial channel; and (4) it was deflected to the west by meeting the overflow of the Ohio from the east. An intimate knowledge of the conditions along other portions of the Wabash, as well as the Illinois, Missouri, and Mississippi rivers, would very likely furnish valuable evidence bearing on the probable conditions, but in the absence of such knowledge, nothing definite can be stated beyond the fact that, if the area under discussion is considered by itself, it would appear most probable that the position of the current was due to a combination of the last two or perhaps of all but the first of the postulated conditions.

The excessive accumulation of the marl-loess near New Harmony appears to have been due to the presence there of a high rock and morainal ridge parallel to the Wabash valley and reaching occasionally above the 500-foot level. This ridge not only formed a nucleus for the deposition, but was the cause of slack water conditions especially favorable to the accumulation of the silts. The absence of the marl-loess as a recognizable type beyond a moderate distance (5 to 8 miles) from the Wabash valley is thought possibly to be due to the failure of the silt-laden currents to pass through into the almost inclosed body of water lying to the east behind and protected by the rocky barrier mentioned.

CAUSE OF THE PONDING

There is no evidence in the Wabash region of the cause of the ponding of the waters to the 500-foot level. Among those who have studied the conditions along the Mississippi valley, some have suggested local barriers due to warping, but no reliable evidence appears to have been presented. A general depression of the northern portion of the United States relative to the land to the south across which the waters eventually had to pass, and due to or at least accompanying the Iowan ice-sheet, is perhaps not improbable, although it is very difficult to prove. The loess terraces, plains, etcetera, described* by Bain, Call, Calvin, Chamberlin and Salisbury, Hayden, Hershey, McGee, Todd, and White suggest that similar conditions existed over considerable portions of the Mississippi basin.

DERIVATION OF THE MATERIALS

The absence of probable sources, either to the east or to the west, seems to make it clear that, as has been already pointed out, the mate-

* See papers 1, 4, 6, 11, 15, 21, 28, 29, 30, 31, and 32 of bibliography at end of this paper.

rial was not of local origin, but was brought down by the rivers themselves. The ultimate source, as indicated by the composition, as well as by partial direct tracing, was in the glacial ice of the Iowan sheet to the north.

Derivation of the Loess of the Common Type

EVIDENCES POINTING TO AQUEOUS ACCUMULATION OF PART OF THE LOESS

General statement.—In the introduction it was suggested that the silts included under the common type are possibly not all of the same origin. While, considered as a whole, the common loess of southern Indiana and Illinois appears to be very largely of eolian origin, there are certain portions lying outside of the limits of marl-loess which, though exhibiting the non-calcareous composition, the clayey texture, and the buff, brownish, or reddish colors of the typical eolian loess, have, nevertheless, a number of peculiarities of composition and topography which are suggestive of aqueous accumulation. These features are considered in the following paragraphs.

Large pebbles.—A considerable number of instances were noted in the Boonville quadrangle of glacial pebbles apparently occurring in the loess of the common type outside the glacial limits. They were of the weathered type, such as occur in the characteristic Illinoian drift a little farther north. The pebbles, which varied from 2 to 5 inches in diameter, were obtained from the ordinary weathered roadside exposures; hence it can not be stated with absolute certainty that they were found *in situ*, though the considerable number noted is suggestive that such was probably the case, especially as none of the number found bore any evidences of human handling, and were of an entirely different character from the fresh Wisconsin gravels sometimes used as road metal near the cities. None were found above an altitude of 500 feet above tide, though this is not so significant here as in the case of the marl-loess farther west, as very little of the land rises above this level in the quadrangle mentioned.

Loess-covered till plains.—Southwest of Petersburg there are extensive plains standing at 500 feet above tide. The main mass of these Pleistocene deposits, which sometimes reach 100 feet or more in thickness, is composed of glacial drift, largely till, but the surface is everywhere covered by a mantle of brownish loess. The stream channels which cut into the plains show that, although the loess surface is nearly flat, the underlying till is marked, as indicated by the varying thickness of the loess mantle, by a surface of gentle but distinct undulations. The filling of the depressions and the upbuilding from the uneven surface of a level plain is not in accordance with the mode of occurrence of the loess above

the 500-foot level in the same region, no loess flats being found at altitudes higher than 500 feet above tide. The type of accumulation on the till plain is not therefore that which would naturally be expected from a gradual and therefore necessarily uniform settling of an exceedingly fine dust on an originally undulating plain, or from silts swept along the ground by the winds as in the case of the not very uncommon loess dunes, but is rather that which characterizes aqueous accumulation. In this connection it may be of interest to note that a single exposure of fossiliferous material of the marl-loess type was observed at the base of the common loess at the edge of the bluff facing the White River flats, 3 or 4 miles west of Petersburg, indicating that the base of the silt mantle is almost certainly of aqueous origin.

Loess-covered aqueous deposits.—During the maximum extension of the Illinoian ice-lobe a glacial lake of some size, known as lake Patoka, occupied the valley and lowlands bordering the present Patoka river, in Dubois and Pike counties, to the southeast of Petersburg. In this lake deposits accumulated to an elevation a trifle less than 500 feet, the elevation probably being fixed by one of the divides, of which there are several, to the south or southwest of the lake. These deposits are now covered by loess. Although sufficient well data have not been obtained to determine with certainty the details of the variations in thickness of this loess mantle, the roadside exposures appear to indicate variations of several, if not many, feet. The loess surface, leaving out of account the post-Iowan cutting, is as nearly an absolute flat as can be readily imagined, there being considerable areas where not the slightest inequalities can be detected by the eye. The irregularities in the thickness of the loess represent therefore the presence of depressions in the underlying surface, due either to original inequalities or to stream erosion in Sangamon times. As in the case of the mantle of the till plain described above, the perfect loess plain is such as would appear to be more characteristic of aqueous than of eolian deposition.

Silt flats.—There are many points both within and without the glacial boundary in the Petersburg and Boonville quadrangles where there are somewhat extensive and approximately level crests standing at the 500-foot level. These, though in the main dependent on the underlying surface, are more regular than the latter and have the appearance of being due to the same agency as those producing the flat surfaces of the silts overlying the till plains and the Lake Patoka deposits.

Silted divides.—Throughout southwestern Indiana and outside of the marl-loess area there are a considerable number of rather broad and flat divides of loess of the common type at an altitude of 500 feet above tide. These are especially numerous in the region within a radius of 5

miles to the south of Oakland City, there being, in fact, not less than 5 or 6 such divides in the 8-mile stretch between the high hills south of Francisco and the south fork of Patoka river. The elevation of the divides is determined by the silts with which they are covered, though the rock is usually not far from the surface. While these elevations may possibly represent a local baselevel of a middle or late Tertiary erosion cycle, it seems more likely, because of their agreement in altitude with the marl-loess limit and with the silt flats both on the till area and on the late Patoka deposits, that they should be referred to some agency limited upward by the altitude mentioned.

Probable conditions of accumulation.—Notwithstanding the distinct differences between the physical character and chemical composition of the common and the marl-loess types, it is believed that the evidence of the flats and silted divides at the uniform altitude of 500 feet, the association of at least one point with fossiliferous marl-loess, and the probable occurrence of pebbles, points on the whole to the aqueous hypothesis as the one best explaining the features mentioned, and appears to warrant the provisional reference of the portions of the loess of the common type possessing these peculiar features to an aqueous origin. This supposed aqueous division of the common loess can probably be traced only along a relatively narrow belt just outside the limits of the marl-loess, though an inconsiderable and unrecognizable portion of the silts for a considerable distance back from the marl-loess belt may be of this type. The great mass of the material lying beyond the marl-loess limits is not, as will be explained, of this origin.

The absence of visible stratification in the aqueous division of the loess of the common type may be considered as resulting from the prevalence of uniform conditions, the locations of the deposits being such that they were in general unaffected by the currents of the White, Wabash, and Ohio rivers, and received additions only from the exceedingly fine and slowly settling silts which still remained in suspension after the deposition of the coarser marl-loess near the rivers. During the deposition, if our view of the origin is correct, there were doubtless many fluctuations of the fluvio-lacustrine level, by means of which the slowly accumulating silts were exposed to the weather and oxidized and the fossils, if ever present, removed by solution. In the case of the marl-loess, on the other hand, accumulation was certainly far more rapid, sufficiently, it is thought, so that a given layer of silt or shells was covered and protected before oxidation or solution had time to materially affect them.

It seems almost certain, however, that parts of the loess of the flats and divides, though accumulating in water, must have been derived, at

least in part, indirectly through the agency of wind, which picked up the finer materials during fluctuations of water level from the deposits along the Wabash valley and transported them eastward.

PROBABLE EOLIAN DERIVATION OF THE MAIN LOESS ACCUMULATIONS

With the exceptions of the belt of the marl-loess and that of the supposed aqueous division of the loess of the common type, both of which are of extremely restricted area as compared with the loess sheet as a whole, the great mass of the silts are lacking in features suggestive of aqueous origin. The presence of these silts at all altitudes up to the highest the region affords (640 feet), the absence of fossils, the absence of stratification, and the lack of definite topographic forms all point to an accumulation through an agency other than that which governed the deposition of the marl-loess. This agency is believed to have been the winds.

An examination of eastern Edwards county, Illinois, shows that beyond a distance of 15 miles there is a general lack of silts of the loess type, showing the source of the material could not have been to the westward; neither can the material have come from the Wabash itself under conditions in any way approximating those existing at present, for under such conditions the maximum accumulations would be along the immediate borders of the valley. The fact that the common loess is sometimes entirely absent along the immediate tops of the bluffs facing the Wabash on the east side, but begins to appear within a short distance, and for several miles rapidly increases in thickness, and then slowly but persistently decreases, suggests that the marl-loess along the Wabash and White rivers was the source of the material. The agency which brought about the accumulation we believe to have been the westerly winds blowing across the marl-loess beds which were exposed during periodic fluctuations of the water level.

As has been pointed out, the common and marl loess types are essentially contemporaneous, and for that reason it has been assumed that the marked degree of leaching and oxidation exhibited by the former as compared with the latter type at similar depths below the surface is due to weathering processes acting during its accumulation. Under the postulated conditions of wind accumulation, ample time and opportunity for the weathering of the material and the removal of the shells by leaching is afforded. The surface was doubtless covered by vegetation, which would not only aid in these processes, but would, in the case of the finer silts in question, tend to counteract any tendency toward lamination during the deposition. It would not, however, prevent the broader

banding effects which sometimes occur concentric with the surfaces of the underlying rock or till nuclei.

If, as we have assumed, the oxidation is dependent on the manner of deposition, it would naturally be expected that, providing the accumulation took place in the absence of vegetation and with sufficient rapidity, unleached and unoxidized deposits identical, except for the horizontal stratification and topographic expression with the marl-loess, would be found. The necessary conditions, with one exception, appear never to have been completely fulfilled, for at only one point, namely, on the hills 2½ miles northwest of Owensville, has eolian silt resembling the marl-loess in its unleached and unoxidized character been found. The silt at this point reaches nearly to the crest of the hill at 540 feet, and is indistinguishable from the marl-loess in color, texture, and in the amount of lime present. No fossils were found, though there is no reason, unless because of an absence of vegetation, why gasteropods should not have originally been present. No stratification was observed. Between this eolian type of marl-loess and the common loess there are many gradations, though most exposures show a closer resemblance to the latter than to the former.

Conclusions

In summarizing the paper it may be said that the writers divide the loess of the lower Wabash valley and vicinity into two distinct types—(1) the marl-loess type and (2) the common-loess type. The first is regarded as practically always of aqueous origin, as far as the region in question is concerned, only one instance of probable eolian loess of this type having been observed. The common loess, while it can not be subdivided on physical and chemical grounds, has been separated into two portions on the basis of its topographic expression. Those portions occurring in a belt just outside the marl-loess deposits and marked by the flats and silted divides 500-foot level are thought to be probably in the main of aqueous origin, while the great mass of silts forming the general mantle covering southern Indiana and Illinois are considered as being of eolian origin. The conclusions are regarded as being probably applicable to the general loess sheet of southeastern Illinois and southwestern Indiana, but should not be extended to more remote regions.

The widely varying views held by different geologists, and especially the variation in the character of the evidence cited in the support of their theories, would seem to make it almost beyond question that the arguments are not everywhere based on the same class of deposits. The view

that the loess silts were carried southward from the Iowan ice by sluggish but variable streams, and finally deposited as extensive flats, from which vast quantities were taken up and redistributed by the winds, was ably presented by Professor Chamberlin,* and is now quite generally accepted. The time for generalization as to origin of the loess as a whole from observations in a single region appears to have passed, and the origin in each locality is best decided for itself by its own internal or physiographic evidence.

In arguing for the aqueous origin of the Wabash marl-loess the writers are but following the views of most of the earlier writers, but they differ from all except Owen,† in differentiating the marl-loess of the immediate Wabash valley from the common or upland loess on either side and in basing their arguments upon the physical and chemical characters and the topographic expression of the deposits themselves rather than on a general assumption as to the conditions or on generalizations as to the origin of the loess as a whole.

Although the literature of the loess contains many descriptions of material apparently similar to that along the Wabash river, it is not permissible to assume a similar mode of origin without a full and careful study of all the evidence which the deposits themselves afford. If the evidences cited in the foregoing portions of the paper should prove to be of any value, they may afford some aid in the discrimination of aqueous and eolian deposits.

References to Literature

The following list, though known to be incomplete, gives some of the more important papers presenting evidences similar to those described in the present paper:

Stratification and horizontal Banding

1. Bain, H. F.: Geology of Plymouth county (Iowa). Iowa Geological Survey, volume 8, 1897, pages 318–366.
2. Beyer, S. W.: Geology of Marshall county (Iowa). Iowa Geological Survey, volume 7, 1896, pages 197–262.
3. Broadhead, G. C.: Origin of the loess. American Journal of Science, third series ,volume 18, 1879, pages 427–428.
4. Chamberlin, T. C., and R. D. Salisbury: Preliminary paper on the driftless area of the Upper Mississippi valley. United States Geological Survey, Sixth Annual Report, 1885, pages 199–322.

*Supplementary hypothesis respecting the origin of the loess of the Mississippi valley. Jour. Geol., vol. 5, pp. 794–802.

† Indiana Geol. Survey, Second Rept., p. 5, 1838. The marl is apparently recognized as a distinct type of deposit.

5. Hayden, F. V.: First Annual Report of the United States Geological Survey of the Territories, 1867. Loess is discussed on pages 10, 12, 18, and 19.
6. Hershey, O. H.: Upland loess of Missouri; its mode of formation. American Geologist, volume 25, 1900, pages 369–374.
7. Hilgard, E. W.: The loess of the Mississippi valley and the eolian hypothesis. American Journal of Science, third series, volume 18, 1879, pages 106–112.
8. Leonard, A. G.: Geology of Dallas county (Iowa). Iowa Geological Survey, volume 8, 1897, pages 51–118.
9. Leverett, Frank: On the significance of the white clays of the Ohio region. American Geologist, volume 10, 1892, pages 18–24.
10. Leverett, Frank: The Illinois glacial lobe. United States Geological Survey, monograph 38, 1899, pages 156–184. A differentiation of the loess was made by Leverett in an earlier report. Report of Illinois Board of World's Eair Commissioners, 1895, pages 77–92.
11. McGee, W J: The Pleistocene history of northeastern Iowa. United States Geological Survey, Eleventh Annual Report, 1890, part i, pages 199–577.
12. Norton, W. H.: Geology of Scott county (Iowa). Iowa Geological Survey, volume 9, 1898, pages 389–519.
13. Safford, Jas. M.: Geology of Tennessee, Nashville, 1869. Loess is discussed on pages 114, 433, and 434.
14. Shimek, B.: A theory of the loess. Iowa Academy of Sciences, Proceedings, volume 3, 1895, pages 82–89.
15. Todd, J. E.: Degradation of the loess. Iowa Academy of Sciences, Proceedings, volume 5, 1897, pages 46–51.
16. Todd, J. E.: On the annual deposit of the Missouri river during the Post-Pliocene. American Association for the Advancement of Science, Proceedings, volume 26, 1877, pages 287–291.
17. Todd, J. E.: The moraines of southeastern South Dakota and the attendant deposits. United States Geological Survey, Bulletin 158, 1899.
18. Wilder, F. A.: Geology of Lyon and Sioux counties (Iowa). Iowa Geological Survey, volume 10, 1899, pages 81–155.
19. Witter, F. M.; Some additional observations on the loess in and about Muscatine (Iowa). Iowa Academy of Sciences, Proceedings, 1887–1889, page 45.
20. Whitney, Milton: Examination of soils from Illinois. Report of Illinois Board of World's Fair Commissioners, 1895, pages 93–114.

Interstratified Sands and Gravels

Papers 1, 2, 3, 7, 9, 10, 11, and 12 in the list of references on stratification also contain allusions to interstratified sands and gravels. Among other papers referring to the same features are the following:

21. Calvin, Samuel: Geology of Delaware county (Iowa). Iowa Geological Survey, volume 8, 1897, pages 118–199.
22. Calvin, Samuel: Geology of Page county (Iowa). Iowa Geological Survey, volume 11, 1900, pages 397–460.
23. Norton, W. H.: Geology of Cedar county (Iowa). Iowa Geological Survey, volume 11, 1900, pages 279–396.
24. Udden, J. A.: Geology of Muscatine county (Iowa). Iowa Geological Survey, volume 9, 1898, pages 247–380.

Boulders and Pebbles in Loess

Papers 10, 11, 12, 19, and 23 of the preceding lists also contain allusions to the occurrence of pebbles or boulders in loess. Additional references are as follows:

25. Bain, H. F.: Geology of Carroll county (Iowa). Iowa Geological Survey, volume 9, 1898, pages 51–107.
26. Mabry, T. O.: The brown or yellow loam of northern Mississippi and its relation to the northern drift. Journal of Geology, volume 6, 1898, pages 273–302.
27. Shimek, B.: Additional observations on the surface deposits in Iowa. Iowa Academy of Sciences, Proceedings, volume 4, 1896, pages 68–72.
28. Udden, J. A.: Geology of Pottawattamie county (Iowa). Iowa Geological Survey, volume 11, 1900, pages 197–277.

Loess Plains and Terraces, uniform upper limits, etcetera

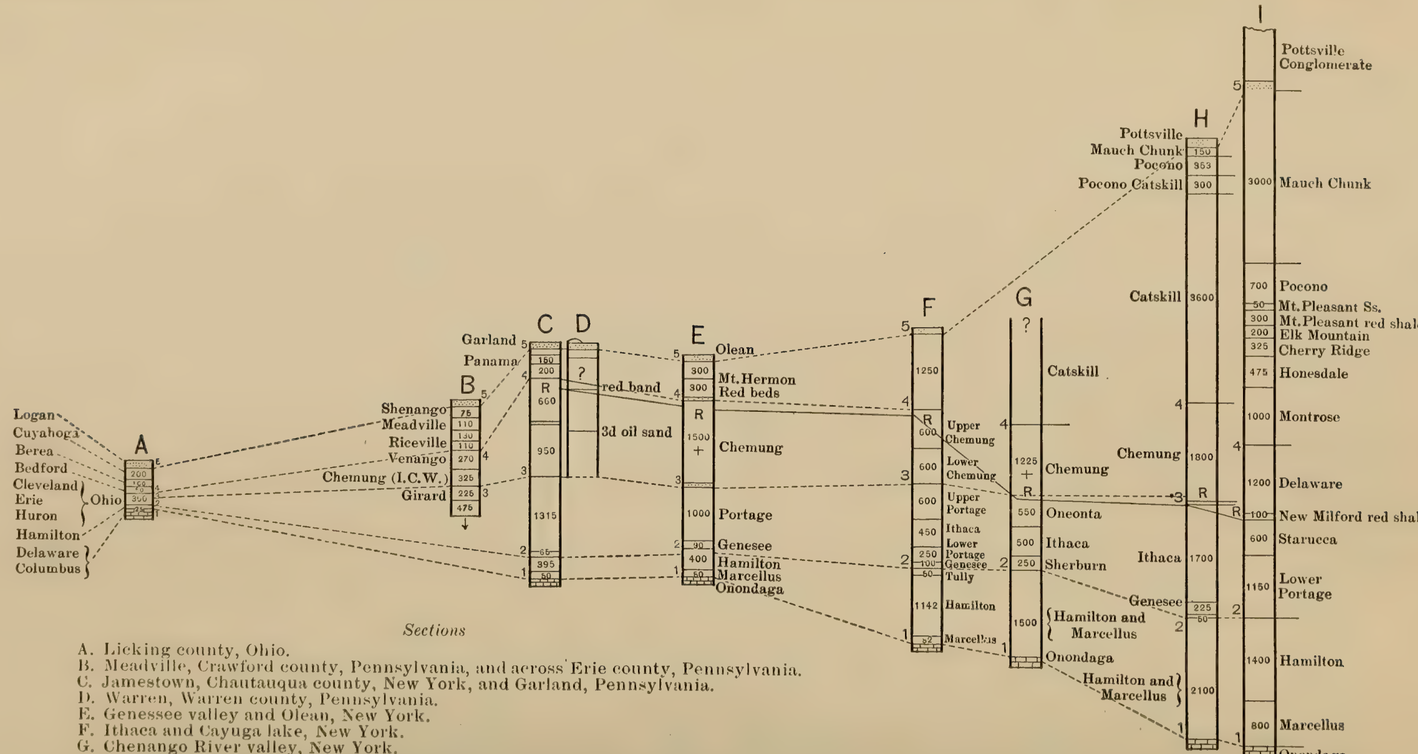
See papers 1, 4, 6, 11, 15, and 21 for reference to loess plains, terraces, etcetera, in addition to the following:

29. Call, R. E.: The loess in central Iowa. American Naturalist, volume 15, 1881, pages 782–784.
30. Hayden, F. V.: United States Geological Survey of Wyoming and Contiguous Territories, 1870. Discusses loess on pages 98 and 99.
31. Hershey, O. H.: Loess formation of the Mississippi river. Science, new series, volume 5, 1897, pages 768–770.
32. Todd, J. E.: Pleistocene problems in America. Geological Society of America Bulletin, volume 5, 1894, pages 531–548
33. White, C. A.: Iowa Geological Survey, volume 1, 1870.

Valley Silts of the Marl-loess Type

See papers 21 and 23 and also the following:

34. Savage, T. E.: Geology of Henry county (Iowa). Iowa Geological Survey, volume 12, 1901, pages 237–302.
35. Udden, J. A.: Geology of Jefferson county (Iowa). Iowa Geological Survey, volume 12, 1901, pages 355–438.



Sections

A. Licking county, Ohio.
B. Meadville, Crawford county, Pennsylvania, and across Erie county, Pennsylvania.
C. Jamestown, Chautauqua county, New York, and Garland, Pennsylvania.
D. Warren, Warren county, Pennsylvania.
E. Genessee valley and Olean, New York.
F. Ithaca and Cayuga lake, New York.
G. Chenango River valley, New York.
H. Catawissa, Columbia county, Pennsylvania.
I. Monroe and Pike counties, along Delaware river, Pennsylvania.

COMPARATIVE CHART OF DEVONIAN SECTIONS

Representing range and distribution of fossil faunas through the formations from the top of the Onondaga limestone to base of the Olean conglomerate and its supposed equivalents in a series of sections extending from Licking county, Ohio, to Monroe county, Pennsylvania

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA

VOL. 14, PP. 177-190, PL. 16 APRIL 30, 1903

SHIFTING OF FAUNAS AS A PROBLEM OF STRATIGRAPHIC GEOLOGY*

BY HENRY SHALER WILLIAMS

(*Read before the Society December 30, 1902*)

CONTENTS

Importance of Fossils to the Geologist

The geologist dealing with stratified rocks has two quite distinct tasks before him. He is called upon to distinguish, define, and name the

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various rock formations. For this task he has small need of help from the paleontologist. His second task, however, is more difficult—that is, the classification and correlation of his formations after they have been defined. For this task the work of the paleontologist is in most cases indispensable. The order of sequence may be a means of classifying formations in a continuous section, but so soon as the continuity is broken, either by faulting or by concealment of the rocks under surficial cover, fossils are required for identification of the particular division of one section which may be repeated in the next. Formations differ, from place to place, in the various characters by which they are defined, and because likeness of definition alone does not furnish a reliable means of classification, geologists have adopted the principle of classifying them on the basis of supposed contemporaneity of deposition. Fossils are the means of determining this contemporaneity. Huxley called our attention to the fact that formations supposed to be contemporaneous on the basis of fossil evidence may not in fact be contemporaneous, but that only homotaxis—that is, like order of succession, can be proven by likeness of the fossils. When rocks from two distinct geologic provinces are compared, this is undoubtedly true in general; but whether equivalent formations be regarded as contemporaneous or only homotaxial, the determination of their equivalency rests on the evidence of their fossils. If the range of all fossil species were restricted within the limits of the formations in which they are commonly found, it would be a simple matter to classify formations by their fossils, and to assign each formation its exact place in a standard time scale. The facts are in evidence, however, to show that species which in one section are so restricted in two successive formations, in another section may occur together, thus proving that in part of their life-history they were contemporaneous.

Fossil Faunas and their Movements

In the following remarks illustrations will be given of the way in which, recognizing the lack of perfect conformity between the formational limits and the range of their common species, the combination of fossils we call faunas becomes a more delicate test of contemporaneity than individual species, and how the movements of the faunas themselves may be used directly in classifying the formations carrying them. The examples are taken from a series of Devonian sections in the states of New York, Pennsylvania, and Ohio. The accompanying chart represents the range and distribution of the fossil faunas through a series of formations, extending from the top of the Onondaga to the

base of the Olean conglomerate and its supposed equivalents, in a series of sections extending from Licking county, Ohio, to Monroe county, Pennsylvania.

Explanations of the Comparative Chart of Sections

The sections are in order from west to east, namely:

A. Licking county, Ohio.
B. Meadville, Crawford county, Pennsylvania, and across Erie county, Pennsylvania.
C. Jamestown, Chautauqua county, New York, and Garland, Pennsylvania.
D. Warren, Warren county, Pennsylvania.
E. Genesee valley and Olean, New York.
F. Ithaca and Cayuga lake, New York.
G. Chenango River valley, New York.
H. Catawissa, Columbia county, Pennsylvania.
I. Monroe and Pike counties, along Delaware river, Pennsylvania.

The measurements and names of formations of the sections are based on official survey reports, and the range of fossils in them has been revised chiefly by those whose names are given below:

Section A. Revised Ohio survey section, Orton, Herrick, and Prosser.
B. I. C. White, Second Pennsylvania, Q4; revision, E. M. Kindle and H. S. Williams.
C. G. D. Harris and Carll, I 4, Second Pennsylvania; range, E. M. Kindle.
D. Carll, I 4, Second Pennsylvania; range, E. M. Kindle and H. S. Williams.
E. H. S. Williams and E. M. Kindle; section revised by M. L. Fuller (U. S. Geological Survey).
F. H. S. Williams, E. M. Kindle, H. F. Cleland.
G. C. S. Prosser and H. S. Williams.
H. I. C. White, Second Pennsylvania, G 7; revised paleontology, E. M. Kindle.
I. I. C. White, Second Pennsylvania, G 6; revised paleontology, C. S. Prosser.

The sections are arranged in order along a curved line extending from Licking county, Ohio; first northeastward toward Jamestown; thence eastward to Ithaca; thence nearly east to Norwich; thence southeastward to the Delaware Water Gap near Strondsburg. On such a line the sections are placed in approximately the relative distances apart which they occupy in nature, such a line theoretically representing a section at right angles across the successive zones of conditions extending out from a shore which had a general trend parallel to the Atlantic coast, northeast and southwest. The total distance is about 500 miles.

The cross-lines connecting the sections, and marked from below upward 1, 2, 3, 4, 5, are the limits of range of the several faunas in their purity:

The dotted line marked 1 represents the upper range of the fauna of the Onondaga limestone;

2 represents the upper limit of the pure Hamilton fauna. (I will use throughout the familiar name of the formation, in which the fauna is typical as the name of the fauna in each case.)

3 is the lower limit of the Chemung fauna;

4, for the western sections, is the lower limit of the Waverly faunas. In the Ithaca section (*F*) and the sections farther east it is the highest level at which definite traces of the Chemung fauna have been detected.

5 is the base of the Olean conglomerate (*E*) and of other conglomerates which have been regarded by stratigraphers as its equivalents. In the east, at section I, it is called Pottsville conglomerate series.

The line marked R represents first appearance of red sediments.

Change in Thickness of Formations and its Meaning

It will be observed that the total thickness of the columns increases at an approximately uniform rate from west to east. The thickness from the top of the Devonian limestone to the base of the Logan group in central Ohio is 675 feet. The total thickness from the top of the Onondaga limestone to the base of the Pottsville conglomerate series in Monroe county, Pennsylvania, is 11,300 feet, a gain of 16 times the thickness of sediment in a distance of 500 miles. The increase of the Hamilton and Marcellus of section C to the same formations in section I is from 445 to 2,200 feet, which is an increase of about fivefold. The increase for the whole section between these two points is from 4,100 to 11,300, or about threefold. The thickness of the sediments through which Genesee, Portage, and Chemung fossils range in section A is 300 feet; the range of these same faunas in the section I is at least 4,000 feet. These comparisons will indicate that the difference in thickness is due chiefly to more rapid and greater accumulation of sediments at the eastern than at the western ends of the line surveyed, with an approximately regular increase all along the line, and a continuance of the relative difference throughout the time expressed by the total sedimentation.

The evidence may be reasonably interpreted into the assumption that during the time represented the chief source of the sediments was from the eastward, and therefore that we may assume that the positions which

the sections occupy in relation to each other express approximately their relative distances from a shoreline to the eastward. The letter *R* is placed at the point of first considerable deposition of red sediments for the eastern sections. It will be observed that this is over 7,000 feet down in section I, about 6,000 in H, 3,000 or 4,000 down in G, 1,200 in F, and 300 in E. Where these red sediments prevail the marine faunas cease, and fossil fish and plants and some invertebrates which are supposed to have lived in brackish water occur. In relation to the marine faunas this horizon, at which pure marine conditions were cut off, occurs at an increasingly later period for each successive section on passing westward. This fact may be interpreted as evidence that the shoreline gradually advanced westward with the passage of time, at least after the appearance of the New Milford red shales in the Monroe county, Pennsylvania, section (I) (see R of section I).

The three Types of Sediments and their Associated Faunas

A. THE RED SHALES AND SANDSTONES

The sediments may be classed in three types or facies, to use the classification of Renevier in his "Chronographie Geologique."

Type A includes the red shales and sandstones, such as are seen in the Montrose, Oneonta, Catskill, and Mauch Chunk formations. These, it will be observed, are at the eastern end of the series. There they are not in evidence at the bottom, but as we pass upward they first appear in the easternmost sections; then farther west, and at the top of the series have reached nearly to the westernmost of the sections. They carry a fish fauna, *Holoptychius*, a few invertebrate fossils and plants, and appear to have been rapidly accumulated and in an estuary, or at least on not fully marine bottom. Far to the east, in Maine and New Brunswick, similar sediments, with a similar fauna and flora, occupy all that part of the column which is occupied in New York by formations between the Oriskany and Carboniferous. In that region no marine faunas corresponding to the marine faunas of the Devonian of New York occur of younger age than Oriskany.

B. THE ARGILLACEOUS SHALES AND FINE GRAINED SANDSTONES

Type B, the second type of sediments, is represented by the rocks of the Hamilton, Ithaca, Chemung, and Waverly formations. They are alternating argillaceous shales and fine grained sandstones, bearing a rich and varied marine fauna. At the bottom they are best represented in the easternmost sections, but they also transgress westward as we as

cend the series. The Hamilton is richest, and occupies the thickest series of strata, in the eastern sections; the Ithaca fauna occupies the second stage of these sediments in the Chenango and Ithaca sections, and does not reach much westward of the latter section at that stage. The Chemung stage does not appear in the two easternmost sections, except in a few rare places where it is interleaved with the dominant Catskill sediments; it is dominant in the central sections, and almost disappears in the extreme western section. As a type of sediment, it is wanting there, but a few of its species do appear in the fine shales called Erie or Ohio shales. The fourth stage of this class of sediments, in the western Pennsylvania and Ohio sections, includes the Waverly fauna, and the eastern limit of the fauna scarcely reaches the Olean section, though a rare specimen representative of the fauna is occasionally seen as far east as McKean and Potter counties, Pennsylvania.

C. THE FINE MUD SHALES

Type C, the third type of sediments, is a very fine mud shale, sometimes arenaceous, but dominantly argillaceous, in fine, thin layers, and very evenly bedded; with a sparse fauna of small, frail shells; the brachiopods, chiefly lingulas, discinas, and chonetes; a few delicate lamellibranchs, but goniatites and cephalopods dominant, and in some places very large, peculiar types of fish occur. The sediments are either light gray or black in color; when black, there are evidences of marine plants, as if a floating sargasso sea were present which dropped its carbonaceous matter on the smooth bottom. This class of sediments is recognized in the Marcellus, Genesee, Huron, Erie, Girard, and Cleveland shales, and, slightly modified, in the Portage shales. This type dominates the western sections; reaches farthest east in the Marcellus stage; only to the Chenango section in the Genesee and Portage stages; appears only in the western New York sections in Chemung time, and is restricted to western Pennsylvania and Ohio at the top. These sediments dominate the whole of the Ohio section, and to the southward, in Kentucky, Tennessee, and in southwestern Virginia they attain a maximum thickness of several hundred feet, forming a continuous black shale from the horizon of the Onondaga fauna up to the Knobstones—the first formation of the Carboniferous of that region.

The Shifting of Faunas

In the region represented by the sections of the chart, these three types of sediments and their respective faunas always bear the same

geographical relation to each other at each successive chronologic stage, and, as has been noted in describing them, each is crowded to the westward as we pass up the series. It is this gradual movement of the whole set of faunas, coördinate with the changing of the sediments, to which the term shifting of faunas is applied. It will be readily seen that this shifting differs from what is generally spoken of as migration of species. By migration I would understand such movements of species as are seen in the cases of the entrance into these faunas of *Spirifer levis*, *Pugnax pugnus*, *Productella hallana*, forms which are common in the Iowa Devonian fauna and dominate the Devonian faunas of Nevada and Arizona, but have no forerunners in the eastern Middle Devonian, entering it abruptly at the time of the Ithaca fauna of New York province.

Preservation of the Integrity of a Fauna

In shifting, the faunas do not lose their integrity, but the whole body of species becomes slightly modified. So long as the fauna occupies the same ground, with its center of distribution or metropolis the same, the species suffer very little modification and range through a thousand feet or more without variation. Where the shifting has moved the metropolis 50 miles or more, the decided modification of species is recognized, though some species are affected more than others. It is the keeping together of the great bulk of the species (a fact which makes it difficult to recognize their movement) which characterizes this shifting of faunas.

Evidences on which this Investigation rests

It has required the accumulation of a vast number of local, individual faunules and their exact analysis and comparison to make it possible to demonstrate the fact of shifting in the present case. Over 5,000 such faunules in the Devonian laboratory of the Survey and reports by competent investigators of thousands more constitute the basis of evidence* upon which the statements here made rest. The second group of these faunas, associated with the Hamilton, Ithaca, Chemung, and Waverly formations, is the one whose statistics are most fully gathered.

Relation of Extent of Range of Species to Metropolis of Fauna

In each case the species of each stage range higher in the region of its center of distribution, or metropolis, than at its edges. West of Ithaca

*A fuller presentation of the facts and their discussion will appear in a forthcoming bulletin (210) of the U. S. Geological Survey.

scarcely a single Hamilton species occurs above the Tully limestone or the base of the Genesee. In the Chenango section and farther east Hamilton species dominate up to the base of the Oneonta, and even after it are frequent. In the Chenango section they appear occasionally in the Ithaca group and recur (some of the more dominant species) after the typical Chemung fauna has occupied the ground; so some of the Chemung species range upward as high as the base of the Olean conglomerate, at Olean, and to the top of the Tanners Hill section, at Warren; to within 200 feet of the Sharon conglomerate, at Tidioute; to within 100 feet of the Garland conglomerate, at Garland, lapping over the place of *Syringotheris* by 100 feet and more in several of the sections of this region, and in several places typical *Spirifer disjunctus* has been found in abundance, associated with abundant specimens of *Syringotheris*, large and with fully developed syrinx. In the Meadville sections, however, the Chemung species have not been discovered higher than the Riceville shales, above which the Waverly fauna comes in in its purity. In Licking county, *Syringotheris* does not appear in the lower Waverly faunas, according to Herrick, till the upper part of the Waverly (above the Berea) is reached. *Syringotheris* is also absent from the lower shaly part of the Knobstones of Indiana and Kentucky, according to Doctor Kindle. All these facts are consistent with each other and with the hypothesis that these three types of sediments were being deposited within the same basin, at relatively the same distance from their source, throughout the whole time represented by their sections, and that they contained distinct faunas, which shifted westward with them with the passage of time.

Effect of Shifting on Species

With the shifting the species which succeeded in holding the ground of their original metropolis continued to live on without change, while the new fauna was being developed in the newly occupied territory. There were undoubtedly new species introduced by migration with each succeeding stage of each class of faunas, but many of the new species are undoubtedly mutants of the species of the last dominant fauna of the previous stage. Slight mutations of the species take place whenever the fauna as a whole shifts its place of habitation. Thus, many of the species of the Hamilton, which shifted westward to reappear above the Genesee and lower Portage formations at Ithaca, are clearly mutants of the Hamilton types, while those that occupy the same stratigraphic horizon a hundred miles eastward, where the genetic succession of species

had not been seriously interrupted, suffered little modification. The same rule applies for the Chemung fauna farther west. In McKean and Warren counties, Pennsylvania, where there was presumably a continuous succession of species on the same general ground, those species which survived suffered little modification till the stage which, stratigraphically, is equivalent to the Waverly, as shown by the occasional immigrants from that fauna which appeared in the strata with them. The metropolis for that class of faunas had shifted westward as far as central Ohio, and with the shifting those species which survived suffered mutation.

Homœotopic and heterotopic Faunas

It is to be noted that whenever fossil faunas are used for determining the equivalency of the formations containing them, or, in general, for classifying stratigraphic formations on a time basis, it is by means of the likeness or dissimilarity of the fossils that the correlations are made. The faunas of the Hamilton, Ithaca, Chemung, and Waverly formations differ in the species composing them, but a large majority of the species of each fauna belong to the same or closely allied genera, and hence the several faunas are generically alike. Many of the species of each are so similar that it is reasonable to infer that they are genetically related. The faunas, whenever seen in a continuous section, bear the same order of succession in relation to each other. The center of distribution of each is different and, in general, approximately a hundred miles separates them. At points between these centers of distribution the species of the earlier fauna blend with those of the succeeding faunas of this group, making it difficult to draw a sharp line of separation between the two, and species which are dominant and are in general characteristic of the separate faunas lap over and are found together in the same strata in intermediate regions. Such a group of faunas may be regarded as owing their similarity chiefly to the fact that they have become adjusted to the same or closely similar conditions of environment, and on account of this cause of their likeness may be called *homœotopic* (from the Greek ὅμοιος, similar, and τόπος, place or environment). Thus it would be said that the faunas of the Hamilton, Ithaca, Chemung, and Waverly formations are *homœotopic*, while the faunas of the Hamilton and Genesee are *heterotopic*. So the faunas of the Chemung and Catskill are *heterotopic*. It will be evident to those who have followed what I have said so far that two faunas of this latter kind (*heterotopic*), which are normally adjusted to different types of environment, although they may appear in

abrupt succession in a continuous section. have no genetic relationship to each other, while, on the other hand, two successive faunas belonging to the same environment (that is, homœotopic faunas) will owe whatever differences they present to one of two causes: (1) evolutional change through direct descent, or (2) loss by destruction and gain by immigration of new species.

The horizon marked in a section by transition from one fauna to another whose species are heterotopic is of entirely different value from that marked by the separation between two homæotopic faunas, for, as has been shown, heterotopic faunas may be contemporaneous and yet by shifting appear one above the other in the sections of a region extending over hundreds of miles; yet it is horizons of the first kind that are more frequently selected for the boundaries of formations and faunas, and chiefly because they are more readily recognized by virtue of the stronger contrasts between the faunas below and above.

In conclusion, let me state some of the practical rules regarding the use of fossils as time-markers suggested by these investigations.

Practical Rules for Use of Fossils in Stratigraphy

1. *ABRUPT TRANSITIONS*

Abrupt transitions in a continuous section from one fauna to another, made of entirely different species and genera, which we are accustomed to use in defining the boundary of formations, are of decidedly local and not wide importance in making correlation; and I think I have presented the correct reason for this fact. It is the effect of a mere local shifting of events, for less than a hundred miles it may be, and the two faunas which in the section are brought into sharp contrast, one of them definitely successor to the other, are actually contemporaneous faunas, adjusted to separate conditions of environment—that is, they are heterotopic.

2. *SLIGHT MUTATIONS OF A CONTINUOUS FAUNA*

The second rule is perhaps little more than the converse of the first, namely, the most satisfactory and reliable evidence of definite epochs of time is to be found by the study of the slight mutations which take place in the history of a continuous fauna—that is, a fauna, or series of faunules, whose species are homœotopic—that is, adjusted to like conditions of environment. These mutations are of two kinds: (*a*) Variation in the form of successive descendants of a common ancestry, and

(*b*) variation in the numerical proportion of abundance of the competent species of the fauna.

3. LAPPING OF TWO SUCCESSIVE HOMŒOTOPIC FAUNAS

A third rule of importance, but of less practical value, is the lapping over in time of two successive homœotopic faunas. This has been established to be a fact, and its practical bearing is that it must be recognized as a possibility in classifying formations, though generally a difficult fact to establish, since the lapping will be discovered only where both the faunas are obscure and in a region where the limits of neither fauna is clear or represented by its full quota of species.

4. DETECTION OF STAGES OF MUTATION IN A FAUNA

Having first ascertained by a thorough study of a continuous fauna, in the region in which it is typically represented, what are its abundant and rare species and the nature and extent of the plasticity of its species, it then becomes not a difficult matter to detect slight deviations from its normal characters; and by observing the modifications, both in composition of the fauna and in variation of its species as they occur in long continuous sections, their time values become evident. These stages in the evolutional mutations of a continuous fauna become almost certain evidences of horizons which are not repeated. Often a single specimen will furnish indisputable evidence of mutational conditions which are very limited in range. Examination of the composition of a single faunule and of the varietal modifications presented by common species or traces of species is therefore far more valuable for making chronological diagnosis than the presence of what are supposed to be characteristic species. This precision with which purely evolutional stages of a fauna may be applied is probably due to the fact that they are of shorter duration than the life of any one of its species. The facts appear to warrant the conclusion that some of these transition stages in the evolution of a fauna are coextensive with the geographical distribution of the fauna. The more delicate and satisfactory modifications seem to be directly associated with epochs of shifting of the faunas. The first trace of decided mutation in the form of a common species is often found to be associated with other evidence that there has been a disturbance of the equilibrium of the fauna, and where thoroughly investigated such disturbances have been connected with change in the center of distribution.

5. MUTATION ASSOCIATED WITH RAPID SHIFTING OF A FAUNA

The study of the faunas in question leads to the hypothesis (though more facts should be gathered before adopting the hypothesis as certain)

that mutation of homœotopic faunas chiefly takes place at times of rapid shifting. An example is the case of the Hamilton fauna, which presents very slight change either in its proportionate composition or in the form of its species or in introduction of new species for some thousand feet of section in Cayuga lake, according to Doctor Cleland's analysis of the facts; whereas a little later, at the time of the introduction of the Ithaca fauna, the shifting is from the east to west, and a large number of the species at Ithaca present mutational relations to the Hamilton species which are less marked a hundred miles eastward, where they may have come by direct descent from Hamilton species of the underlying rocks. The same fact is observed in Warren and Crawford counties, Pennsylvania; at the upper range of the Chemung fauna mutation was taking place as the Waverly stage is reached in species which preserved their characteristics so long as the equilibrium of the Chemung fauna was intact.

6. DOMINANT AND CHARACTERISTIC SPECIES

Dominant and characteristic species, so called, must be used with caution in making correlations, for with the shifting of the faunas they preserve their integrity with great persistence, and afterwards will recur long after the fauna to which they belong has by shifting been generally modified and decimated. Examples of this are the recurrence of *Tropidoleptus* and half a dozen other dominant Hamilton species after the Chemung fauna is evolved at the cliffs along Chemung river and at Owego and in Tioga county, New York; also the appearance of *Spirifer disjunctus* and associate species in Warren county, Pennsylvania, over 100 feet above where *Syringotheris* has appeared in abundance, fully developed and in large size.

7. STRATIGRAPHIC SUCCESSION NOT CERTAIN EVIDENCE OF CHRONOLOGIC SUCCESSION OF FAUNAS

The succession of one fauna above another is not certain evidence that the upper fauna is really younger than the lower. This must be regarded as true when we observe the shifting of one fauna locally over another, the two coexisting in the same basin in rocks at a lower level. Thus the Portage and Ithaca faunas are in succession in the Ithaca section, but in the Genesee section the Portage occupies the whole interval from the Genesee to the Chemung.

8. CHRONOLOGIC VALUE OF FIRST APPEARANCE OF A NEW FAUNA

It is probable that the first appearance, on passing upward in a geological section, of new types of fossils is a more accurate and more

widely extended indication of definite point of time than is the last appearance of species of a fauna which has been a long time dominant. To apply this principle practically it will be necessary to select, for marking the transition from one formatian to the next, the horizon of entry of the new fauna into the region rather than the total departure of the old one. When we deal with homœotopic species, it is evident that nowhere will the lines be so sharp as where heterotopic faunas are brought into contact at the division line. Such a fact, as has already been said, cannot be relied on as sharply diagnostic of time.

9. CHRONOLOGIC VALUE OF RELATIVE ABUNDANCE OF SPECIES IN A FAUNA

The stage of life-history of a fauna is indicated with greater precision by the relative proportion maintained by the species in relation to each other than by the presence or absence of the species. A clear example of this law is seen by the analysis of the faunules of the Portage zone of the Chenango section, coming as it does in direct sequence above the Hamilton fauna. Thirty-four of its 41 species were recurrent Hamilton forms, but its dominant list of 11 species contains but one of the species dominant in the Hamilton below, and 5 of this list are species not occurring below, at least 2 of which are clearly mutants of Hamilton species.

Farther west in the Ithaca section only 33 out of 84 species in the fauna are recurrent Hamilton species, and in the expression of the fauna at Ithaca the dominant list of 12 species contains not a single Hamilton dominant species, but all the species of the dominant Hamilton list are present in the Ithaca fauna of Ithaca. This example illustrates the way in which the shifting of the fauna affects it. The fauna is not utterly destroyed, but its equilibrium is badly broken; most of the species continue to live, but the dominant species lose their place; rivals replace them, and with the replacement considerable modification of several species is at once evident.

10. FORMATIONAL EQUIVALENCE NOT IDENTICAL WITH FAUNAL EQUIVALENCE

There is a decided difference between formational equivalence and faunal equivalence. When the term equivalent is meant to signify occupation of the same position in the time scale or series of strata, the facts here presented show that formations may be equivalent (as the Portage, Ithaca, and Oneonta) (or the Chemung of the Olean section and the Catskill of the Catawissa or Monroe County sections), while the faunas

which are characteristic of the equivalent formations are not equivalent. The Portage fauna extends both below and above the known limits of the Ithaca fauna, and the Catskill fauna ranges both below and above the Chemung fauna.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 14, PP. 191-200 MAY 15, 1903

STRATIGRAPHIC RELATIONS OF THE RED BEDS TO THE CARBONIFEROUS AND PERMIAN IN NORTHERN TEXAS*

BY GEORGE I. ADAMS

(Read before the Society December 30, 1902)

CONTENTS

Red Beds of Eastern Oklahoma

In June, 1901, the writer made a reconnaissance from Kansas into Oklahoma, for the purpose of studying the relations of the limestones of the Carboniferous and Permian of Kansas to the shales and sandstones known as the Red beds. The results of this trip were briefly summarized in the *American Journal of Science*,† under the title "The Carboniferous and Permian age of the Red beds of eastern Oklahoma from stratigraphic evidence." As there stated, it was found that the limestones which are conspicuous in the Kansas section thin southward, and gradually disappear, so that south of the Arkansas river in Indian territory and Oklahoma the section consists of shales and sandstones. The transition in the character of the formations is accompanied in the upper part of the section by a change to a maroon or red color. The approximate limit of the red color in this region is, accordingly, a line diagonal to the strike of the formations. The portion of the Red beds in strike with the Carboniferous limestones is therefore of Carboniferous age, and the

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†Vol. xii, p. 383.

portion in strike with the Permian limestones is of Permian age. The stratigraphy of the Red beds is difficult to study because of the absence of conspicuous horizons and the general absence of fossils. It is believed, however, that the results of the reconnaissance supply a correct interpretation of the beds and furnish a basis for future detailed study of them.

After having arrived at the conclusions above stated concerning the relation of the Red beds in Oklahoma, the writer was impressed with the idea that similar features might be found in northern Texas. Accordingly a trip was made in the month of October, 1902, for the purpose of reviewing that field and studying the critical points in the mapping which had been done by the Texas survey. The writer was accompanied by Mr Bailey Willis during a portion of the time, and has had the benefit of his criticism and suggestions.

Results of Cummins's Investigations

The relation of the Carboniferous and Permian limestones of northern Texas to the Red beds in that region as first explained by Mr W. F. Cummins,* of the Texas survey, has never appeared wholly satisfactory. The accompanying sketch map (figure 1) has been prepared from the published maps and sections made by the Texas survey. It will be observed that certain of the divisions of the Carboniferous seem to have been differentiated by correlating sections made across the strike of the beds, and that the sections in the northern part of the field do not tie to each other. Mr Cummins first expressed doubt as to the accuracy of his earlier mapping,† and finally reviewed the field in part and supplied a more satisfactory interpretation. His conclusions, which are corroborated by the results of the writer's reconnaissance, are stated by him in a preliminary paper,‡ but his fuller paper has not yet been printed by the Texas survey. It is not proposed here to review the somewhat conflicting statements which have been published concerning the relation of the Albany and Cisco to the Wichita and Clearfork divisions, but to proceed at once to the interpretation of the stratigraphy which was arrived at from a study of the field.

Reconnaissance in northern Texas

It was considered advisable to examine at several points the Carboniferous-Permian contact as mapped by Mr Cummins in the second annual

* Report of geology of northwest Texas. Second Annual Rep't Texas Survey, 1890, pp. 359-555.
† Texas Survey, vol. iv, p. 223.
‡ Trans. Tex. Acad. Sci., 1897, p. 93.

Figure 1.—*Sketch Map of lithologic Divisions of the Carboniferous and Permian of northern Texas*

By George I. Adams

report of the Texas survey. Accordingly a reconnaissance was made from Henrietta eastward to the border of the Cretaceous and southward to Bowie, at which place the coal of the Cisco division outcrops. In driving overland it was found that the red color which is predominant around Henrietta extends to the Cretaceous border, although showing somewhat less conspicuously in the more easterly outcrops. The beds, which are sandstones and shales, were seen to have low dips to the northwest. In this part of the field the red color accordingly extends downward in the section nearly to the coal at Bowie, as shown on the accompanying map. No stratigraphic break or division line was observed.

The next point examined was the relation of the Clearfork to the Wichita division. By driving from Bowie to Henrietta and Wichita falls, and thence westward along the Wichita river to Baylor county, and southward to the Salt fork of the Brazos, and eastward to Graham, opportunity was afforded for seeing the formations both along the strike and dip. In Clay, Wichita, and Archer counties the rocks are clays, sandstones, and conglomerates, with occasional calcareous beds, which do not form strata or lenses of limestone, but rather impure, nodular layers. In the northeastern part of Baylor county a thin stratum of limestone was found, which has been described by previous writers as occurring at the old military crossing of the Wichita river and affording invertebrate fossils. The line of outcrop of this bed was followed southward to the Salt fork of the Brazos. From this point the journey to Graham was across the outcrop of the lower beds, and the section revealed considerable change in lithology from what was seen farther north, thin limestones occurring at several horizons.

To the east of Seymour, and higher in the section than the limestone whose outcrop was traversed, there are a number of limestone beds which outcrop conspicuously on the Salt fork of the Brazos. A trip was made from Seymour along the breaks south of the Salt fork into Throckmorton county, thence westward through Throckmorton to the western border of the limestones, and northeastward, returning to Seymour. Within this area the section contains a larger number of limestones than to the northward, and individual beds are heavier and more conspicuous. The writer is convinced that they are equivalent to the limestones of the Albany division to the southward, since they are in strike with the Albany and lithologically similar. This is a verification of the later conclusions of Mr Cummins.

With this point established, it appears that what have been called the Clearfork and Wichita divisions by Mr Cummins are the equivalents, in part at least, of the Albany. To return now to the consideration of the

FIGURE 2.—*Sketch Map of the Carboniferous and Permian of northern Texas*

By A. F. Cummins

map and sections published by the Texas Survey, it will be seen that in drawing the line at the western border of the Carboniferous from Clay county to Young county Mr Cummins was apparently influenced by the occurrence of the red color and the absence of limestones. In locating it in southeastern Haskell county, at which point one of his sections begins, he placed it at the western border of the limestones and the beginning of the typical Red beds.

The approximate limit of the red color, as the writer observed it in Texas (figure 2), is very similar to the line which was drawn in northern Oklahoma. It cuts diagonally across the strike, transgressing more widely in the higher formations. Where the Albany limestones extend northward into Baylor county the red color is not so conspicuous, although it is exhibited in the shales to a considerable extent. It prevails to the west of the Albany limestones as far south as my field work extended.

Age of the Red Beds

The age of the Red beds in northern Texas has usually been considered to be Permian. This opinion has been largely based upon the evidence afforded by vertebrate fossils. A large amount of material from the breaks of the Wichita river has been described by Cope * and other writers, but the exact localities from which the specimens were derived were seldom stated. Some localities which are mentioned are clearly below the horizon of the limestone in northeastern Baylor county, at the old military crossing on the Wichita, from which the cephalopods which are considered of Permian age were obtained by Mr Cummins and described by C. A. White.† As has been shown, this limestone is referable to the Albany division, which has furnished an abundant invertebrate fauna which has been regarded by some as of Permian age, although it is included as a division of the Carboniferous by the Texas survey. Fossil plants have been obtained by Mr Cummins from the head of Godwin creek, in Baylor county, and from 3 miles west of Antelope, Texas. They were studied by Professor William M. Fontaine, who has referred them to the Permian.‡

The results of this reconnaissance contribute little toward the placing of the line between the Carboniferous and Permian in Texas. It is shown, however, that it is possible, by means of the stratigraphy, to determine the relation of the vertebrate and invertebrate faunas and the

* Trans. Amer. Phil. Soc., vol. xvi, pp. 285–288.
† Amer. Nat., vol. xxiii, p. 109.
‡ Bull. Geol. Soc. Am., vol. iii, 1891, p. 217.

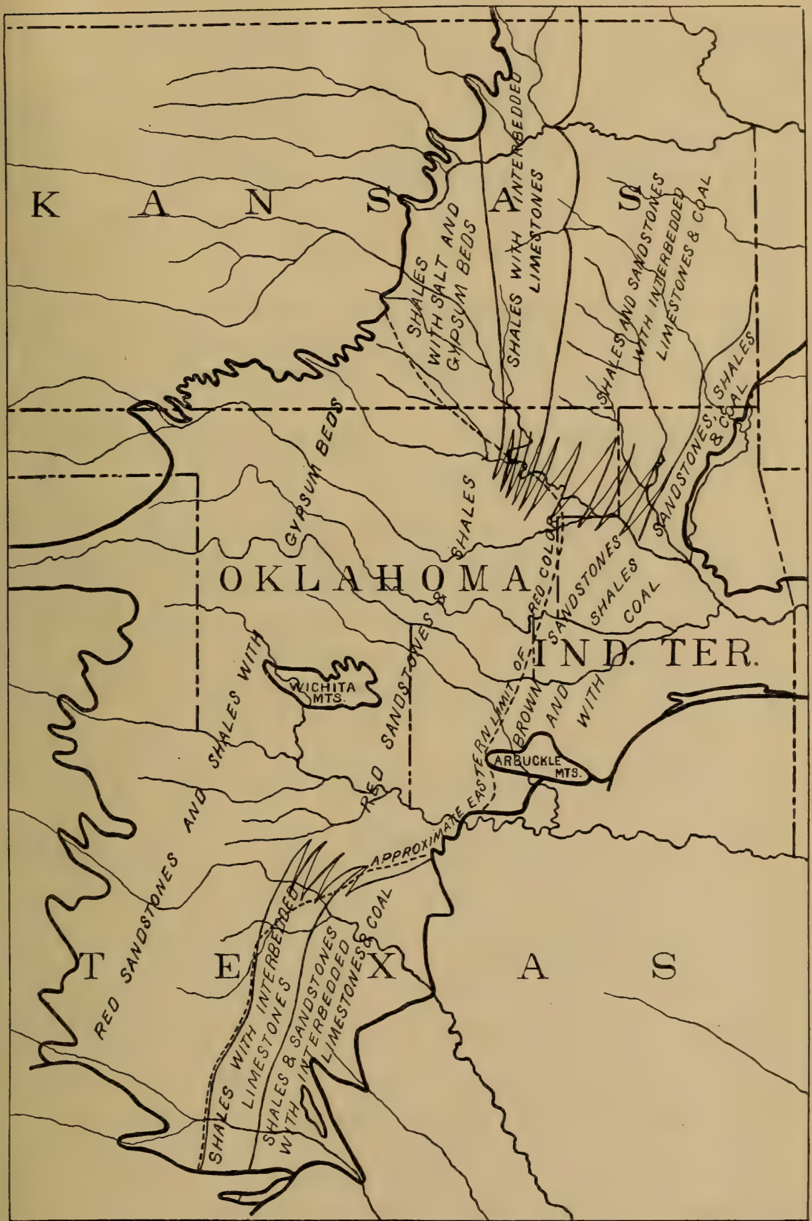


FIGURE 3.—*Sketch map of lithologic Divisions of the Carboniferous and Permian of Kansas, Indian Territory, Oklahoma, and northern Texas*

By George I. Adams

paleoflora to each other, and it is hoped that detailed work which will establish a type section and obtain data concerning the horizons of the fossils will be carried on the coming season. The writer does not attempt to express an opinion in regard to the validity of the Cisco, Albany, and other divisions of the section, but has accepted them as described by Drake in his detailed mapping of the southern part of the field.*

Obsolete Terms

Concerning the divisions of the Wichita, Clearfork, and Double mountain, it may be said that there is little reason to believe that they should be any longer retained, since they have no stratigraphic significance.

Relationships of Red Beds of Texas, Oklahoma, Indian Territory, and Kansas

The relation of the Red Beds in Texas, Oklahoma, Indian Territory, and Kansas is more fully shown on the accompanying map (figure 3), on which the lithologic divisions of the Coal Measures and Permian are outlined. No names are proposed for the lithologic divisions there set forth, it being the intention of the writer to await critical paleontologic studies, in order that the faunal and floral changes may be given due weight in establishing the divisions of the various sections.

Carboniferous and Permian and their Relations

The lowest Coal Measure beds in Arkansas rest on the Lower Carboniferous, and their contact, as exposed northward through Indian territory, southeastern Kansas, and into Missouri, is apparently one of overlap. In southeastern Indian territory the Coal Measure rocks are limited for a considerable distance by a great thrust fault which brings them in contact with the Ordovician. They overlap and rest unconformably on the older Paleozoics, which form the periphery of the Arbuckle mountains. In this region the Coal Measure sediments are largely of local origin. From the Arbuckle mountains southward into Texas the eastern limit is the contact with the overlapping Lower Cretaceous formations. In central Texas they rest for a short distance on the Lower Carboniferous, and thence westward are overlapped by the Lower Cretaceous. The western border of the Permian in Texas and northward to the border of Kansas is the line of contact with the over-

* Report on Colorado coal field. Fourth Ann. Rept. Texas Survey, 1892, pp. 358–481.

lapping Tertiary. This boundary is broken, however, by an arm-like extension of the Red beds which reaches along the Canadian river into New Mexico. In Kansas for a short distance the limit of the Permian is the contact with the overlapping Lower Cretaceous. Thence northward it is overlapped by the Tertiary and farther on by the Upper Cretaceous. Within the area of the Red beds are the Wichita mountains, consisting of igneous and old Paleozoics, which were formerly wholly covered by the red sediments which in this locality were largely of local origin.

The lowest rocks of the Coal Measures are found in western Arkansas and eastern Indian territory. In this area they have a folded structure. In the remaining portion of the field the rocks have low dips to the westward, with the exception of the area immediately south of the Arbuckle mountains and east of the limit of the red color. There the rocks are closely folded. The date of the folding in Arkansas and eastern Indian territory is pre-Cretaceous. It may be pre-Permian; but as to this there is at present no definite evidence. In the small area south of the Arbuckle mountains the folding occurred before the deposition of the red sediments, which lie unconformably on the Coal Measure rocks, and it appears now that it was pre-Permian.

Lithologic Divisions of the Permian and Carboniferous

Considering the character of the sediments of the Carboniferous and Permian in the area here mapped, it is seen that in Arkansas and central Indian territory the sediments consist of sandstones and shales, in which there are coal beds. Going westward the area of the shales and sandstones broadens and extends northward into Kansas and southward into Texas. Lying to the north and south of this central region there are, in Kansas and Texas, as equivalents of the sandstones and shales of the middle portion of the section, lithologic divisions in which limestones are interbedded with the shales and sandstones. These northern and southern divisions bear considerable resemblance to each other. The frequent alternation of shale and sandstone beds with limestones indicates that the conditions of sedimentation in the two areas were quite similar. Their respective faunas have not been studied carefully, but they suggest that the divisions may be correlated tentatively.

It is not proposed to discuss here the source of the Carboniferous and Permian sediments. Two striking features of the map which should be noted, however, are the embayment of the red color to the eastward, the limit being diagonal to the strike of the formations throughout a con-

siderable portion of its extent, and the thinning of the limestones and their gradual disappearance from the section as they strike into the median area. These facts have a bearing on the position and nature of the land areas which existed during Carboniferous and Permian time. However, the general relations of land and sea during this period is a subject which is too broad to be discussed from the evidence afforded by this area alone.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA

VOL. 14, PP. 201-206, PLS. 17-18 MAY 20, 1903

AMES KNOB, NORTH HAVEN, MAINE

BY BAILEY WILLIS

(Read before the Society December 30, 1902)

CONTENTS

INTRODUCTION

GENERAL FEATURES

Penobscot bay, Maine, is a triangular embayment, whose inland apex is the mouth of the Penobscot river, and whose base toward the sea is 30 miles across.* The bay opens to the Atlantic, and the nearest land to the southeast is that of South America and Africa, more than 4,000 miles distant. In the mouth of the bay are many islets and several islands among them the Fox islands,† to which this note specially refers. The features here discussed relate to wave sculpture and ice sculpture, and a brief account of the topography is accordingly appropriate.

TOPOGRAPHY OF FOX ISLANDS

There are two of the Fox islands, as distinguished from islets, North Haven and Vinal Haven, the former lying north of the latter and being separated from it by the Fox Islands thoroughfare, a narrow strait. Their extent is about 10 miles from north to south and 18 miles from

*See chart 104, Penobscot bay, U. S. Coast and Geodetic Survey.

†See chart 311*a*, Fox Island thoroughfare, U. S. Coast and Geodetic Survey.

east to west. The present shores are of very youthful aspect, deeply sinuous in water line, and not conspicuously remodeled by wave action either through the development of sea cliffs or the construction of spits. There is deep water close up to steep rocky shores, and shallows are found chiefly off gently sloping lands. No wave-cut benches of rock or sandbars interrupt the advance of the waves to the shore, though here and there the surf plays about isolated rocks and skerries, which in connection with the deep and crooked channels show how irregular is the submarine surface. The subaerial surface exhibits closely corresponding features of hollows, slopes, and hillocks, which are readily recognized as forms sculptured by brooks and rivulets and modified by glacial erosion and filling. The valleys are well adjusted to weak rocks or to shear zones in massive rocks, and the hills are residual heights maintained by harder masses. The maximum altitudes slightly exceed 200 feet on the northern part of Vinal Haven, and on North Haven one knob, known as Ames, is 150 feet in elevation ; in general, however, the higher lands are from 100 to 140 feet above sea. Lower summits, as well as higher ones, are, as a rule, bare rocks, which protrude through the glacial clay and gravel deposits mantling the slopes. This mantle is so widespread and its surface has been so little modified since the retreat of the ice, that one is impressed with the recency of that event. Neither waves nor streams appear to have accomplished much in the post-glacial interval. Distinct evidences of marine action at considerable height above the present sealevel are therefore noteworthy as evidences probably of Glacial or pre-Glacial times, and some such are presented in the following account of Ames knob.

Features of Ames Knob

ROCK MASSES AND RELIEF

The geology of the Fox islands has been studied by Mr George Otis Smith, and to his account* we are indebted for the facts here made use of. Ames knob and its slopes consist of andesite, which is in general hard and compact. Even where the make-up of the rock is such that it is properly termed a volcanic conglomerate or breccia, the original fragments are firmly cemented. About part of this hard mass of volcanic material occur softer beds of like origin, in which tuffaceous rocks are more common and lavas less so, while on the northern side of the knob occur sedimentary rocks, consisting chiefly of shale and limestone.

* The geology of the Fox islands, Maine; a contribution to the study of old volcanics. Skowhegan, Maine, 1896.

FIGURE 1.—NORTHERN SLOPE OF AMES KNOB, NORTH HAVEN, MAINE

View looking northeast, showing glaciated profile of the Knob and general view of North Haven island

FIGURE 2.—SOUTHEASTERN SLOPE OF AMES KNOB, NORTH HAVEN, MAINE

View looking northeast, showing sea cliff and wave-cut bench 80 feet above sealevel

SLOPES OF AMES KNOB, NORTH HAVEN, MAINE

The relation of relief to these rock masses is direct. The yielding sediments are cut down to a plain, nearly to sealevel, from the southern edge of which the compact andesite rises in a steep bluff about 140 feet high. From the summit to the east, south, and west profiles descend on gentle and roughly uniform slopes of andesitic lava, flattening as they approach the shore, and the irregularities which break their uniformity appear from a distance to be fortuitous effects occasioned by very local variations in the rocks. On nearer view, however, the details of form are found to be significant of conditions of sculpture.

DETAILS OF FORM

The steep northern slope of Ames knob has already been referred to. It is in effect a cliff, the upper portion of which is bare rock, while the lower slope, consisting largely of talus, is covered with trees. It is illustrated in plate 17, figure 1, and the rounded form of the summit, due to glaciation, is strikingly apparent. Strongly contrasting with the profile shown in this view is that on the southern side of the knob, as it appears in plate 17, figure 2. Here we see a cliff, approximately 40 feet high, rising from a sloping bench, which is broken by ridges of rock and strewn with large angular fragments. The altitude of this bench at the base of the cliff is 80 feet above sea. It extends northeastward, south, and southwestward to distances varying from 150 to 200 yards from the base of the summit knob, and its outer margin is marked here and there by prominent ledges rising from 3 to 5 feet or more above the grassy slope. Their altitude is approximately 60 feet above sea, but probably varies 5 or 10 feet either way from this amount. The bench enclosed between them and the base of the highest pinnacle is a much gentler slope than that above or below, and in any profile drawn southward from the summit of Ames knob to the shore it appears as the base of a distinct reentrant angle. That it is not due to a weak layer in the otherwise massive rocks is apparent from the character of the numerous outcropping ledges, which are practically uniform in hardness with the summit. Glaciation has played an important part in modifying the landscape forms of the region, and one might interpret this bench as an effect of ice sculpture, such as we find where a small glacier lingers on a mountain side after the retreat of the general ice-sheet; but such effects are produced in the shadow of a hill, and this slope is exposed to all the force of the southern and southwestern sun. There are many instances on these islands of plucked ledges—that is, ledges whose southeastern or southern face is a surface from which blocks have been torn by the advancing ice, leaving steep jointed faces exposed. The southward-

facing cliff of Ames knob might thus be interpreted, but the wide bench extending from the eastern end around the southern and southwestern sides could not have been produced by such an action. Turning, then, to consider the conditions of marine sculpture, we find that this bench is on the side which would be exposed, almost without protection, to the full sweep of the Atlantic were the islands uniformly submerged 80 feet deeper than now. The heights of Vinal Haven would form a group of islets, which would in some measure break the force of the advancing ocean surges, but they would be too scattered and too small in area to form a protecting barrier.

CONDITIONS AND DATE OF SUBMERGENCE

Pursuing the inference suggested by the above described relations of form and direction, we may consider the land submerged to a depth of 80 feet below its present level, and regard Ames knob as a rocky islet, not unlike the Sugar loaves which are now above water at the western end of the Fox Islands thoroughfare. The islands of Vinal Haven and North Haven were then to a great extent covered by water, and the group presented few land surfaces approaching a square mile in extent. As the general topographic features of Penobscot bay, including the existing submarine channels, are effects of subaerial erosion, it is recognized that the coast has sunk some hundreds of feet below a former high altitude; and it is assumed that the submergence had progressed to the level marked by the bench on Ames knob, but it is possible that the land was for an episode relatively rising. Whatever the relative changes of altitude in reference to sealevel had been, the relation became fixed for a time, during which the waves cut the wide bench which extends from the present 60-foot contour to that at 80 feet above sea. Judged by the features developed along the western shore of Vinal Haven, which are relatively insignificant as compared with this bench, the sea stood long at that position. The writer does not know of any bench of similar width cut in equally hard rocks on this coast in post-Glacial time.

Having recognized that the facts indicate a prolonged episode of submergence, one turns to the rock ledges for some evidence of its date. They bear no glacial striæ, so far as observed, even though the under surfaces of large loose blocks which were partially protected from the weather were examined; yet the ledges resemble in subangular character of profile the glaciated form on the higher knob, and the absence of striæ is easily accounted for by the obvious effects of scaling and of frost and sun. These evidences of ice action upon the supposed wave-cut bench are so general that one is convinced the surface was exposed to glaciation, and it follows that the episode of marine attack preceded

FIGURE 1.—SOUTHERN SLOPE OF AMES KNOB, NORTH HAVEN, MAINE

Showing in profile against the sky a wave-built bar which connects the Knob with an outlying ledge

FIGURE 2.—GRAVEL PIT IN MARINE DEPOSIT OF GLACIAL STUFF

Locality is northeast of Ames knob

SLOPE OF AMES KNOB AND PIT IN GLACIAL GRAVEL

the advance of the ice-sheet over this district. It may have been earlier than or contemporaneous with the initial stages of the latest glacial episode.

Post-Glacial Marine Deposits

Were the above elements of form and sculpture unsupported by evidence of marine sediments, the case could be presented with no stronger conclusion than a probability; but there are such deposits, and they shed additional light on the date of submergence. Two hundred yards south by east from the summit of the knob there is a prominent outlying ledge which is connected with the base of the knob by the long, sloping profile of a wave-built bar (see plate 18, figure 1). Its uniformity is interrupted by many ledges of rock in place, but between them, and particularly toward its lower end, the form of a bar is conspicuous. It is composed of small pebbles, many of them thoroughly waterworn, and the material on the whole resembles that of the occasional pebbly beaches along the present coast. Gravel of similar character is to be detected here and there throughout the pasture slope, but as it could readily be explained as the wash of waters from the glacier, it would not be significant were it not in the same locality built into the unmistakable submarine bar. In the material constituting this bar there are striated stones clearly of glacial origin.

On the northeastern side of the knob, at a point where converging currents sweeping in from the south and southwest would meet in the lee of the rock, there is a shoulder built of gravel at a maximum elevation of about 40 feet above the present sealevel, that is about 20 feet below the old wave-cut bench. A pit, which has been excavated in this bank (plate 18, figure 2), shows the gravels in section, locally exhibiting steep cross-stratification in association with rather heterogeneous piling of stones and sand. The stones are subangular and in some instances striated. From among these stratified layers the writer picked out some tiny fragments of shale, too small for determination and so decayed that they crumbled with the slightest pressure.

These scattered gravels occurring here and there upon the slope, the wave-built spit connecting an outlying ledge with the summit, and the embankment built below the old water-level in the lee of the rock, appear to constitute a set of contemporaneous features, all indicative of submergence during or following soon after the retreat of the ice.

Summary

Ames knob, a mass of uniformly hard andesite, exhibits a peculiar bench, between 60 and 80 feet above the present sealevel, along the

southern slope, in a position exposed to the waves of the Atlantic, were the region submerged to that level. On account of this position, other conditions of sculpture being excluded by various considerations, this bench is attributed to wave action. From its extent it is argued that the duration of submergence was long. Rock ledges outcropping on the bench exhibit glaciated forms, and it is inferred, therefore, that the bench existed at the time of the ice advance. The deposits of gravel, built into a characteristic spit and embankment and containing striated stones, show that the submergence continued or was repeated after the retreat of the ice. Hence it is concluded in general terms that the Fox islands were submerged 80 feet deeper than now at the time of the latest ice advance; that this submergence continued during the occupation of the area by the ice, and that elevation began at a date not long after the retreat of the ice, and proceeded without notable interruption until the sea reached its present level.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 14, PP. 207-226, PLS. 19-20 JULY 7, 1903

SUBMARINE VALLEYS OFF THE AMERICAN COAST AND IN THE NORTH ATLANTIC

BY J. W. SPENCER

(Read before the Society December 31, 1902)

CONTENTS

INTRODUCTION

This paper is intended as a sequel to "Reconstruction of the Antillean Continent,"* in which the submarine valleys of the West Indian region

*Bull. Geol. Soc. Am., vol. 6 (1895), pp. 103–140.

are mapped, but its completion has been postponed, while the writer was engaged on other West Indian and Central American investigations, the results of which have appeared from time to time. In these later papers the details of the submarine topography are elaborated, but no additional studies along the Atlantic coast have been completed, though there is a fragmentary notice of some of the valley-like features.* While the key of the subject is among the West Indian islands and off the coast of Florida and Georgia, the features so repeat themselves farther northward, along the great submarine slope, that they are worthy of careful consideration. So also in the north Atlantic, between Greenland and Europe, the region is full of interest. Although the soundings off the European coast are not made along the most satisfactory lines, or carried far enough, yet the studies of Professor Edward Hull † show the general extension of the deep valleys down the continental slope on the eastern side of the Atlantic basin, and Mr Warren Upham made other studies off the American coast.‡ The submarine basins have been widely studied, but the deep incisions of the great continental slopes have been generally overlooked, although several European writers, in various languages, have described special features, and it is these features which form the present theme. Since these pages were in proof, Dr F. Nansen, of Norway, has shown me similar studies in preparation.

Submerged Plains off the eastern Coast of America §

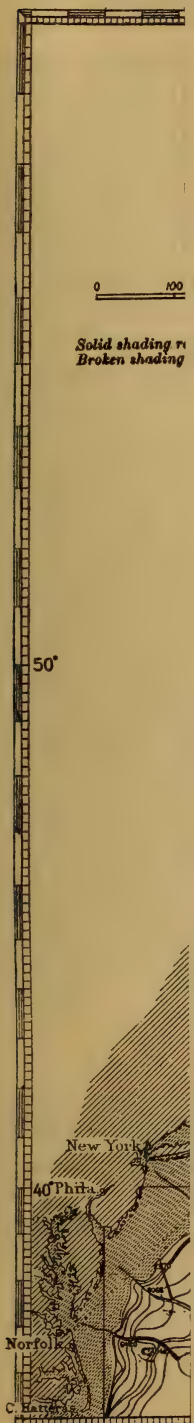
The present topic begins with cape Hatteras and extends to the margin of the Newfoundland banks. Off cape Hatteras the submerged coastal plains are reduced to a breadth of less than 25 miles. They widen to 85 miles off New Jersey, and again south of Rhode Island (Marthas Vineyard), and to considerably more between these localities, especially in front of New York harbor, while they extend 300 miles southeast of Newfoundland. From cape Hatteras to above the latitude off the mouth of Chesapeake bay, the outer edge of the submarine plains is taken to be a line at a depth of 200 to 250 feet below sealevel. Beyond that point it is fringed with a somewhat steeper slope or in places a lower terrace, whose outer margin has a depth of 400 to 450 feet. The chart contour of 600 feet occurs everywhere beyond the margin of the sub-

* Read before the Brit. Assoc. Adv. Sci., 1897 ; Geol. Mag., London, Dec. iv, vol. v. (1898), pp. 35–37.

† "Submerged terraces and river valleys bordering the British isles;" "Suboceanic terraces and river valleys off the coast of western Europe;" "Physical history of the Norwegian fjords," and other papers read before the Victoria Institute and appearing in the Transactions from 1898 till the present year.

‡ Bull. Geol. Soc. Am., vol. 1, 1889, pp. 563–567.

§ See U. S. Hydrographic Charts, no. 1411 and no. 21*a*.


0
100
Solid shading r
Broken shading
50°
New York
40° Phila.
Norfolk
C. Hatteras

SUBMARINE VALLEYS OF THE ATLANTIC COAST

merged plains, and is not their limit, as is popularly stated; but this line shows frequent cove-like indentations or culs-de-sac. For 250 miles eastward of Cape Cod peninsula the sunken plains maintain their general monotonous characteristics, being submerged from 200 to 250 feet with a fringing border covered by an additional 200 feet of water; but north of this submarine peninsula is the broad valley of the gulf of Maine, traversed by channels from the direction of the Kennebec, Penobscot, and Saint Croix rivers, besides that from the bay of Fundy, showing soundings from 720 to 1,080 feet, without reference to the coves or gulfs into which they enter. This region is one of drift deposits, which may give irregularity to the submarine topography, and probably accounts for the obstruction of 200 feet to the valley. South of Nova Scotia this continental border is broken into hills and valleys, showing the remains of typical coastal plains dissected by deep valleys. Between cape Breton and Newfoundland is the Laurentian valley, which will be noticed later. Beyond are the great banks of Newfoundland, extending 300 miles southeast of that island. Here is a remarkable repetition of the features of the coastal plains of the continent, largely represented by extensive flats submerged only 200 to 250 feet and forming a plateau elevated 150 to 250 feet above a lower plain. It is entirely separated from Newfoundland by a broad channel in depth corresponding to the lower plain. In both cases the soundings indicate channels from 60 to 200, and, in some cases, to 300 feet in depth, incising their surfaces. These banks appear to have had the same relationship to Newfoundland that the plains of New Jersey now have to the mountainous zones behind them.

Evidence of channels similar to those of the Newfoundland banks may be found everywhere on the submerged plains, which are manifestly continuations of the present land surfaces, but they are apt to be obstructed by sands carried by the currents or by drift deposits; but these features will be brought out in studying some of the great river channels.

Hudson River Channel

Its character was recognized by Professor James D. Dana as long ago as 1863,* but the features were not fully known until 1891, when Mr A. Lindenkohl † made use of the accumulated soundings and showed that the drowned channel of the Hudson river is clearly traceable across the submarine shelf of the continent. He says that it is first noticeable 12 miles southeast of Sandy Hook, at a depth of 120 feet below the surface

* Dana's Manual of Geology, 1863.

† Am. Jour. Sci., ser. iii, vol. xli, 1889, pp. 489-499, and Report U. S. Coast Survey for same year

of the sea. Farther on, where the coastal plain is submerged 90 feet, the channel is still 90 feet deeper. At 53 miles the channel reaches the depth of 180 feet, with a breadth of two or three miles between the banks, which are here also covered by 90 feet of water. The coastal plain is more and more submerged, until at 91 miles from the Hook its depth is 234 feet; but the channel of the Hudson here is still deeper than above, although it shows only a depth of 48 feet beneath the banks, probably due to partial filling. At 97 miles it begins to assume the form of a canyon, which continues 23 miles farther, to the apparent edge of the continental shelf. The average breadth of the river channel is one and a quarter miles and of the gorge about three miles, with a depth reaching to 2,844 feet, where the coastal plain is submerged only 420 feet. The bottom of the channel and the canyon is covered by a bluish slate-colored mud, with fine sandy grit. At this point Mr Lindenkohl stopped his inquiries. The continuation of the valley beyond, down the continental slope for 140 miles, will be noticed in its proper place (page 214).

Susquehanna and Delaware Channels

The surface of the submerged plain in this region has been so leveled by the shifting sands that Mr Lindenkohl was unable to trace the channels across it, as in the case of the Hudson, but inside of the bays he found them. Thus in the Chesapeake the channel was observed for 35 miles and found to be from one to two miles wide, with a depth from 42 to 108 feet at points where the adjacent banks were submerged to a depth of 48 feet. Below it is filled by sand bars. So also he found the drowned channel of the Delaware from 54 to 108 feet below sealevel, or from 30 to 84 feet deeper than the shoals. The obstruction of the channels by the sands appears to have been due rather to the action of currents in shallow water during epochs of slight changes of level than to their filling in deeper water at a greater distance from the shore. Further evidence of the existence of channels deeply incising the coastal plains, whether above the sealevel or below it, is found by borings which reveal them and show that the modern streams in their lower reaches are flowing over channels, now silted up to depths of 250 feet or more, the most notable being not in this region, but near the mouth of the Mississippi, whose original bed is a thousand feet below sealevel at New Orleans, though for some distance beyond the coastline it is obscured like the channels of the Chesapeake and Delaware. The former courses of these great river valleys again become apparent in the deep coves or canyons incising the edge of the continental slope, which is the principal

subject of this paper to be more fully elaborated. The channel of Narragansett bay is also traceable across the sub-coastal plain.

Laurentian and other Channels

South of Long island and New England evidence of similar channels passing into coves or canyons and gulfs frequently recurs. The gulf of Maine is a broad valley in the submerged plain, with several channels converging toward it, as has been mentioned; but by far the grandest of all the valleys traversing the drowned plains of the continent is that of the Laurentian.

The Laurentian channel from the mouth of the Saguenay extends for 900 statute miles before reaching the edge of the continental shelf. Soundings in the Saguenay fiord reach to a depth of 882 feet, but below this point the Saint Lawrence is filled so as to have a depth of scarcely more than a hundred feet; however, 35 miles farther down it reaches to 702 feet, beyond which the soundings so far taken show a somewhat less depth. A short distance still farther on a depth of 1,128 feet is shown. In the gulf of Saint Lawrence, below the mouth of the river, the depth is 1,368 feet. Even 500 miles beyond this point the incomplete soundings do not reveal a greater depth (1,350 feet), but there are intermediate measurements reaching to 1,878 feet, which show the need of fuller soundings or suggest that the lower part of the course is obstructed probably in part by drift. For the last 140 miles before reaching the edge of the continental shelf the soundings do not touch the bottom, and consequently are insufficient for knowledge of the full depth. Eventually they show that the valley enters a deep amphitheater or gulf indenting the border of the continental mass. The floor of the gulf of Saint Lawrence is generally submerged from 200 to 250 feet, or where it has been dissected the depth may be 200 feet greater, as on the margins of the coastal plains or banks. Through this floor the course of the Laurentian valley is strongly marked, and has a general breadth from 50 to 70 miles, or somewhat greater where the tributaries enter it, the most important being the twin valleys from the north of Anticosti (Anticostian) and that from the straits of Belle isle (Esquiman), north of Newfoundland. This valley has already been previously described by the writer,* being the first of his papers on submarine valleys.

Another class of channels incising the submerged plains should be noted. These are the fiords extending from the bays of Newfoundland. Thus that of Placentia bay has a depth of 846 feet and that of Trinity

*J. W. Spencer: High elevations preceding the Pleistocene period [in America]. Bull. Geol. Soc. Am., vol. 1, 1889.

bay 1,494 feet, with their courses apparently obstructed to the amount of 300 and 600 feet, supposedly by drift deposits, in a manner not seen among the channels in more southern latitudes. But fuller soundings may reveal the course of the valleys without so much apparent obstruction. Evidence also appears of the existence of several fiords extending from Newfoundland across the banks, but the soundings are not full enough to work out the old hydrography. A valley (the Labradoran) trending northward from the straits of Belle isle, between Newfoundland and Labrador, is shown to a depth of 1,500 feet, and Hamilton inlet, in Labrador, reaches to 1,800 feet, with its lower portion seemingly blocked in part. These apparent obstructions by drift deposits are of much value as showing that the valleys were formed before the epoch of glacial drift. This inference as to the age of the buried valleys may be carried farther south.

Among the shallower soundings of the Laurentian valley, already explained by either insufficient exploration or to drift filling, those reaching to about 1,800 feet sufficiently establish that the general depth of the valley throughout the greater portion of its length is equal to this amount, while the channels through the gulf of Maine are not known to have exceeded 1,100 feet. Such valleys continue to within a few miles of the edge of the continental margin, where they are abruptly precipitated into coves, ampitheaters, or gulfs.

The submarine valleys mentioned are continuations of those of existing rivers. Others are not traceable to the modern rivers, because submergence even to their sources, as the Cansoan valley, which heads in the straits of Canso, and the Esquiman and Labradoran, which approach each other in common in the col, now sunken to form the straits of Belle isle, between Newfoundland and the continent. So also the banks of Newfoundland are nearly dissected by the Lesleyan and Hullian bays, all of which are now beneath the Atlantic waters.

Characteristics of the submerged Continental Slope

IN GENERAL

From the narrowed continental shelf off cape Hatteras there is a rapid descent to 3,096 feet in 7 miles, and then to 9,582 feet in the next 6 miles, without the revelation of any intermediate ledges. This is the most abrupt descent shown in the continental slope. North of this point both the submerged coastal plain and the great continental slope widen rapidly, as they do southward. Off Nova Scotia the zone of descent is somewhat reduced in breadth, and at some points off the Newfoundland banks

it becomes precipitous, which is like that near Flemish cap, off cape Hatteras. At various points are suggestions of submarine plateaus in the slope, owing to the occurrence of somewhat extensive plains with only slight gradients—for example, southeast of New Jersey, between the contours of 9,000 and 10,500 feet, which are here some 60 miles apart.

SUSQUEHANNAN VALLEY

In the margin of the continental shelf in front of Chesapeake bay there is a strongly marked indentation corresponding to it. Here at some distance within the 600 line connecting the promontories on its two sides the depression or valley reaches depths of 4,686 and 5,154 feet, enclosing a cul-de-sac or gulf, having a still farther descent to 6,420 feet below sealevel. Some 15 miles farther outward the valley reaches to more than 9,846 feet, thus making known another abrupt step in it. From this point the valley descends only about 900 feet in the next 30 or 40 miles, but it has a depth of 1,500 feet below the floor of the adjacent continental slope. In this locality an outlying fragment of a submarine plateau appears at about 5,000 feet below sealevel, and overhangs by nearly 5,000 feet the adjacent valley to the north ; but the valley bends round to the east of this promontory, where it has descended to the great depth of 8,000 feet below this fragment of a submarine tableland, and has a depth of 12,840 feet below sealevel at a distance of 60 miles from the head of the cul-de-sac or cove, indenting the edge of the continental shelf. About 30 miles farther it enters an embayment shown by the 15,000-foot line. This embayment has a length of 150 miles and a breadth of 70 miles, with a depth from 1,200 to 2,400 feet below the floor of the lower plains of the continental slope. Thus the Susquehannan valley occurs all the way down to oceanic depths.

THE DELAWAREAN VALLEY

Mr Lindenkohl first called attention to a cul-de-sac of 2,376 feet inside the 600-foot contour in front of Delaware bay. At a point about 95 miles from cape May, in the same direction, incomplete soundings show the valley reaches to 3,000 feet below sealevel, where the adjacent continental slope is only 1,200 feet below the surface, and 10 miles farther the depth of the channel is 6,066 feet, or about 1,200 feet deeper than the neighboring sea bottom. For the next 90 miles the valley is shown in the contours, and at this distance its depth is 11,256 feet below sealevel, or more than 1,000 feet deeper than the adjacent continental slope. Some 50 miles farther it enters the Susquehannan embayment, as already mentioned. A little farther north than that of the Delaware, Mr Lindenkohl

found another cove or gulf at 2,334 feet, which is probably a tributary of the Delawarean valley from Great Egg harbor.

The contoured chart brings out prominently the submarine peninsula extending far seaward and separating the Susquehannan embayment from that of the Hudson.

THE HUDSONIAN VALLEY

Mr Lindenkohl gives the head of the Hudson canyon at 97 miles from Sandy Hook, and in the next 23 miles shows that it descends from 234 to 2,844 feet (see page 210). The soundings in the line of the Hudson channel beyond this point are unfortunately scanty, but from those on either side, when connected by the intermediate contours drawn in the usual way, parallel with the inner lines, the continuation of the valley may be inferred by the evidence of an embayment between 11,400 and 15,000 feet below sealevel, and in a distance of about 110 miles the descent is found to be 8,500 feet from the bottom of the cul-de-sac above mentioned, which is already nearly 3,000 feet below sealevel.

In front of Narragansett bay there is a strong embayment in the 9,000-foot contour, and here are several closely located soundings showing the indentation of the continental slope. This valley seems to be a tributary to the Hudsonian embayment.

THE FUNDIAN VALLEY

Some distance eastward of the Cape Cod peninsula the continental slope is narrowed to a zone of 50 miles, and here south off the Georges shoals the edge of the submerged coastal plain is indented by two great gulfs, one of which has a depth of 2,520 feet below the adjacent promontory (which is 5,580 feet below sealevel, while the great cove is 8,100 feet). The other cul-de-sac shows 1,860 feet inside the 600-foot line and farther on descends to 6,702 feet, while the bounding promontory, even 10 miles or more beyond, is covered by a reduced depth of 5,802 feet of water. Eastward of this point we reach the canyon of the Fundian valley, which across the submarine coastal plain has already been described. Its well marked channel at this point descends abruptly into the canyon, which heads in an amphitheater having a depth of 4,080 * feet, 10 miles within the 600-foot line. In the next 15 miles the descent reaches to 6,984 feet. In another 30 miles its depth is 9,000 feet, and at least 1,200 feet deeper than the adjacent sea floor. An indentation in the lower zone of the continental slope corresponding with the valley is plainly shown at 15,000 feet.

* This is a recent sounding, here used in place of 3,510 shown on map.

A short distance east of the Fundian canyon there is a fine cove deeply indenting the edge of the submerged coastal plain at 600 feet, with a depth of 3,648 feet.

THE CANSOAN VALLEY

The Cansoan valley, though interrupted by apparent drift deposits, has a depth of 1,080 to 1,200 feet across the coastal plain, after which it rapidly descends to 7,020 feet into a cove more than 2,000 feet deeper than the adjacent floor to the southwest of it.

THE LAURENTIAN VALLEY

On reaching the edge of the continentel shelf, like the other valleys it descends into an amphitheater 3,666 feet deep. This may be found to be not the deepest part of a canyon-like valley when closer soundings are taken, as was the case with the Fundian valley. Unfortunately the soundings are few, and the continuation can not be located, but there are several soundings which show a strong indentation in the continental slope to a depth of 15,000 feet. From Placentia bay, Newfoundland, a valley also passes over the margin of the banks by way of an amphitheater or cove.

VALLEYS OFF THE NEWFOUNDLAND BANKS

Southeast of the Great bank the descending valley is seen within the 600-foot line at 3,120, at 11,100 (where it is 2,520 feet below the adjacent submerged cliff), and again it appears at 12,738 feet, indenting the 12,000-foot line. Another similar valley occurs just north of this one, where the cove reaches to 4,944 feet, while the adjacent shelf is only 690 feet below sealevel. This valley is also traceable down the slope. Flemish cap is the highest flat of the submerged bank of the most eastern extension of the continental mass. In this locality the great slope descends very rapidly to oceanic depths; but even here we find evidence of a cul-de-sac of 5,000 to 6,000 feet deep. Between Flemish cap and the Great bank the submerged plateau is deeply indented on both sides by large valleys or embayments, which are here named Lesleyan bay (after Professor J. P. Lesley, one of the originators of geomorphy), and Hullian bay (after Professor Edward Hull, who has made similar studies on the eastern side of the Atlantic). Northeast of Newfoundland banks other valleys appear even among the scanty soundings, though there seems to be more refilling by drift accumulations than on the other side of the plateau. Thus while the fiord of Trinity bay attains a depth of 1,488 feet, it is not seen across the banks, while an adjacent one reaches to

2,430 feet, where the lateral bank is only 1,020 feet below sealevel. While the drowned col in the straits of Belle Isle is 240 feet below sea-level and the Labradoran channel (here so named) trends northeastward and is seen to become a valley at a depth of 1,500 feet, the soundings are too few to mark its further course. From the same col, but extending southeastward, is the Esquiman channel, joining the Laurentian valley.

SOME FEATURES OF THE CONTINENTAL SLOPE

It is notable that the embayments into the continental slope in front of the great valleys mentioned are much deeper than would be suggested by the outline of the present shores. The approximation of the Lesleyan and Hullian bays indenting the opposite sides of the last stretch of the submarine continuation of the American continent is such a feature as characterizes the atmospheric erosion of tablelands with their ultimate dissection into separated plateaus. The cul-de-sac, coves, or gulfs are found to indent the border of the continental mass for distances of 8 to 20 miles or more, and even the incomplete soundings show that their width is reduced to even 3 miles, but they enter lower embayments, widening to 5, 10, or even 20 miles or more when far seaward, but yet no wider than the lower reaches of valleys of existing rivers.

The declivities of some of the greater valleys observed do not show a greater slope than about 100 feet per mile. Except for short tributaries from plateau regions, this is too large an amount for normal valleys. The data are insufficient to work out the gradients, as has been done in the case of the Floridian channel, where it is often about a foot per mile for long distances, succeeded by rapid descents from one step to another. However, we find everywhere in the coves or gulfs, indenting the margin of the drowned continental shelves, the evidence of abrupt or rapid descent from step to step, although we do not know the gradients between them or of the further descent of the valleys. Such submarine features are repetitions of what may be seen on the tablelands of Mexico and Central America, with the slopes between the steps greatly reduced.

Geological Characteristics of the Region traversed by the Valleys

From the occurrence of the geological formations of the adjacent coastal plains some inferences of the character of the submerged plains may be formed, which to some extent are sustained by the direct evidence of the materials brought up by the dredges. Thus we can form an idea of the age of the valleys.

From New Jersey onward to Newfoundland, surface deposits of drift

are to a greater or less extent developed, and these partially obstruct the valleys (pages 211, 214, 215). Off cape Hatteras, dredgings bring up quantities of old Miocene water-worn shells mixed with modern species. Miocene beds occur in Maryland and New Jersey, while they have been removed from Long island, which is surmounted by drift; but fragments of Miocene beds recur in Marthas Vineyard, and have been recovered by dredgings from depths of 35 to 70 fathoms, off the Georges shoals, south of the gulf of Maine. The same have been found on the Banquereau, southeast of cape Breton, adjacent to the Laurentian channel. Again Tertiary fossils have been obtained from the great bank of Newfoundland (latitude 44 degrees 30 minutes, longitude 50 degrees 15 minutes). While the drowned plains off Maryland and New Jersey are covered by sands, these do not appear in the Hudson channel, as it incises the continental shelf, for here is found a fine blue clay. It thus appears that the completion of the valleys of the submarine coastal plain has been since the old Miocene period, and their origin, due to atmospheric erosion during a period of land elevation, may not be questioned. The great Laurentian valley doubtless owes part of its origin to a much earlier date, but while it is excavated out of all the formations represented since Archæan times, it cuts through Carboniferous and Triassic rocks, and consequently is of later date. As has been shown by Professor W J McGee,* the great period of erosion was after the accumulation of Lafayette formation, and these deposits, as the writer has seen, underlie the drift of New Jersey. The Lafayette was accumulated after a long period of Tertiary erosion of this region, and is provisionally regarded as of late Pliocene age. Doctor Dall has shown that some fossiliferous beds beneath the Dismal swamp of Virginia are referable to the Pliocene period. The pre-Lafayette erosion gave rise to flattened topography of the old Miocene surface. The formation of the channels of the Coastal plain, or their reopening, was after the Lafayette period, or early Pleistocene epoch, when the fiords of Newfoundland and Nova Scotia were fashioned, but prior to the accumulation of the drift or the Columbia formation, both of which kinds of deposits rest on the post-Lafayette topographic surfaces.

From the continuity of the continental shelf with the coastal plain and the occurrence of similar formations on the outlying banks, one is led to conclude that the plains, whether now above or below sealevel, form one feature, and that the sands, more or less filling the valleys, is only such a feature as would be produced by the slight changes of level that have occurred since the mid-Pleistocene epoch. It is also interesting to note that the banks of Newfoundland, which show the same character of submarine plains as in the region south of the drift, are not so

* The Lafayette.

covered with it as to prevent the recovery of Tertiary deposits and establish the common origin of these plains with those existing in New Jersey.

Some Valleys of the North Atlantic and adjacent Arctic Basins*

VALLEYS BETWEEN GREENLAND AND AMERICA

The soundings beyond the Newfoundland banks are insufficient for study. One line between Labrador and Greenland shows a rapid descent from the continental shelf (here less than a thousand feet below sealevel) to 5,220, and farther on to 9,732 feet, beyond which the descent is more gradual to the depth of 12,196 feet, which is in the center of the arm of the Atlantic basin between Greenland and the continent. Between Greenland and the southern point of Baffins Land the depth is reduced to 8,100 feet, and a little farther northward to 6,600 feet, though there may be a deeper channel not made known. In latitute 66 degrees the soundings are numerous and show fragments of the Greenland coastal plain, even to a breadth of 70 miles, with a submergence of less than 300 feet, while the trough in Davis straits, except in narrow channels, is reduced to 2,160 or 2,270 feet. Here is the col between the arm of the Atlantic basin and Baffin bay, in which, nearby, are culs-de-sac, one reaching to 3,996 feet, with the bay beyond, having a depth of 6,000 feet, and another 5,580 feet within the 1,700-foot contour line. The soundings are moderately numerous and show magnificent fiords to depths of 4,000 feet. While at first sight the soundings here suggest that Baffin bay is a distinct basin, yet upon second consideration, owing to a considerable part of the bay having only a moderate depth, this apparent form may be due to partial obstruction of the straits by glacial or iceberg deposits or to the soundings being insufficient to reveal a restricted valley beneath this narrowed arm of the sea. Some of the deep tributary fiords, however, are not refilled with drift to the point of distinction, as off Newfoundland and Norway.

The maximum depth of the lower part of Hudson straits is unknown, except that it is more than 1,800 feet deep at several points, while several hundred miles westward it is 1,200 feet, and Hudson bay, even near its outlet, much less. The upper part of Hamilton inlet has a depth of 600 feet, but the coastal plain in front, much of which is shallow, is not known to be covered by more than 200 feet of water.

VALLEYS BETWEEN GREENLAND AND SCOTLAND

The soundings in this belt are numerous and full of interest. While there are many illustrations of the oceanic basin wherein the submarine

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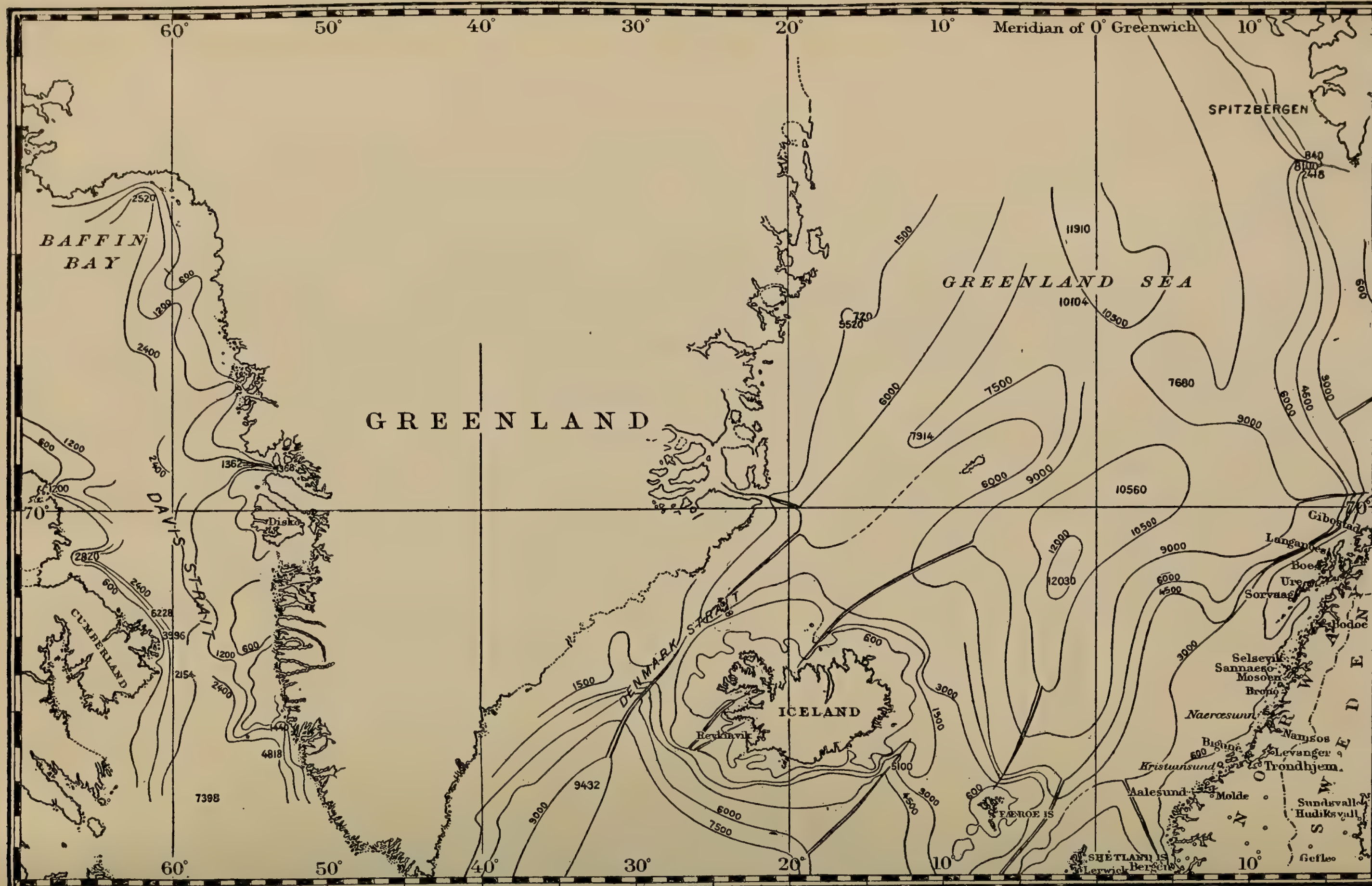
*See the U. S. Hydrographic Charts, nos. 21*a*, 21*b*, 318, 1531.



SUBMARINE VALLEYS OF THE NORTH ATLANTIC AND ARCTIC BASINS

Soundings and contours in feet

plateau of this region is shown, the writers have given no attention to the relatively small valleys, in size and characters like those of rivers, too small to be represented on the ordinary maps, except by undue exaggeration. It is these valleys and their enlargement into submarine bays which are the principal source of interest to the writer. In this region the North Atlantic plateau (the Wyville-Thomson ridge) rises to separate its basin from that of the Arctic.

Iceland is bordered by a subcoastal plain, on the west reaching to a breadth of 70 miles; but it is deeply indented by submerged valleys, one of which is 648 feet near its head, where the adjacent floor is submerged only 84 feet. This canyon is traceable for 60 miles, with a depth of 600 feet below the coastal shelf itself, and then widens into an embayment. Similar features are repeated round the whole island, some of which are shown on the map (plate 20). From recently made Danish soundings it would seem that the great fiord traced (see map) north of Iceland should enter the Arctic embayment west of that shown on map as the one with which it connects. Doctor Nansen is now extending these studies.

Between Greenland and Iceland the submarine plateau rises to within about 1,500 feet of sealevel. except in a channel where the depth attains 1,968 feet. The submarine plateau is here incised by amphitheaters, coves, or gulfs to the depth of 600 to 1,200 feet, and these widen out and become very deep valleys. Thus one can be traced from the col for 150 miles, where its depth becomes 3,000 or 4,000 feet below the submarine plateau. The fiord of Scoresby sound has a depth of 1,800 feet far within the landlocked mouth. Its lower part does not show so great a depth, supposedly on account of glacial or iceberg drift. In latitude 74 degrees north is a finely shown cove attaining a depth of 5,520 feet, where the adjacent plateau is submerged 720 feet.

VALLEYS BETWEEN ICELAND AND THE FAROE ISLANDS

Between Iceland and the Faroe islands the plateau reaches to within 1,500 to 1,662 feet of sealevel. Near Iceland it is incised by a fine cul-de-sac, obtaining a depth of 4,092 feet, where the floor at its head is 960 feet below the surface, and beside it 2,100 feet; thus the submarine valley itself has a depth of 1,992 feet. North of Faroe islands is an embayment reaching to a depth of 7,290 feet, while an extension of the plateau toward the east is covered by 1,224 feet of water. Near Iceland the southern side of this ridge is marked by another cul-de-sac at a depth of 4,092 feet below the surface, or some 2,000 feet deep in the plateau itself.

VALLEYS BETWEEN THE FAROE AND SHETLAND ISLANDS

Between Faroe islands and the Shetlands the North Atlantic plateau is more deeply incised than in the stretches to the westward. Here is an

incision in the so named Lightning channel with a breadth of 30 miles, where the col is submerged to a depth of 3,180 feet. From this trough a valley descends northward to the Arctic basin, and one with more rapid gradient to the deep Atlantic arm between the Rockall banks and Scotland, which has been mentioned by Professor Hull and others, as has also the Sognefjord (over 4,000 feet deep), a tributary of the Arctic basin.*

The troughs of the Arctic basin expand and deepen west of Spitzbergen, where a depth of 15,900 feet is reached (latitude 78 degrees 30 minutes), and beyond this Nansen did the greatest Arctic work in finding the continental slope bordering the Eurasian continent, and thereby establishing almost with certainty the absence of polar lands. Even the occasional soundings show finely the occurrence of a great cove southwest of Spitzbergen, which obtains a depth of 8,100 feet, where the plateau beside it is only 2,418 feet below sealevel, and at the head of it, 10 miles landward, the depth is reduced to 800 feet. An amphitheater in the continental shelf off Tromsoe, Norway, attains a depth of 5,100 feet where the adjacent sounding is only 1,494 feet. This northern basin is most interesting and suggestive. It is modified by islands and sunken plateaus, like the Caribbean and gulf of Mexico basins, and its features as far as known are in harmony with the tropical ones between the two Americas.

VALLEYS BETWEEN AMERICA AND BRITISH ISLES

Between America and the British isles the North Atlantic plateau rises to the summit described. There are a few troughs which show arms of the Atlantic basin deeply indenting it, enough to suggest that when fuller soundings are made south of the Icelandic ridge valleys trending from that ridge may be traceable to the indentations of valley form at depths of 12,000 feet in about latitude 52 degrees, made known by cable soundings. Similar suggestions of deep valleys or embayments appear northwestward of the ridge of the Azores.

On the Origin of the Submarine Valleys

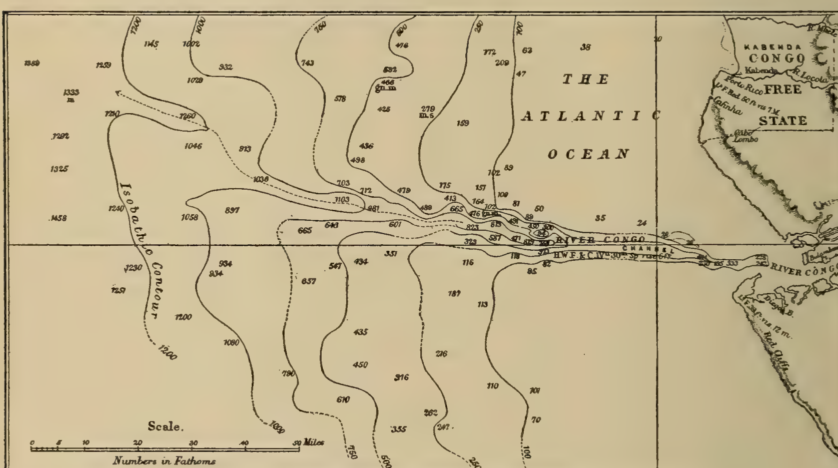
The origin of submarine valleys attaining a depth of even 1,000 or 2,000 feet in the continental shelf, and whose outer edge is submerged 300 or 400 feet, although implying a recent elevation of 2,000 or 3,000 feet, need scarcely be called into question. While these channels pass through canyons and descend abruptly into the deeper valleys which open out into embayments in the great continental slope to depths of

*See Professor Hull's papers cited before.

12,000 or 15,000 feet, it may seem difficult to explain these lower reaches by the hypothesis of atmospheric action during a period of emergence on account of the stupendous changes of level of land and sea required; yet the writer has ventured to adopt this hypothesis, in which he has been confirmed by many years of research. But from the broad standpoint the complex conditions doubtless qualify the simple hypothesis of the former elevation of the land with its consequent sculpturing by atmospheric agents. While some of the valleys may be attributed to tectonic or orogenic, or occasional ones to volcanic causes, no explanation based on these causes has been worked out in detail; consequently the author has been led, after presenting the facts given in this and other papers, to emphasize particularly the resemblances between these submarine valleys and land features, with the conclusion that the former were sculptured on the great continental slopes by atmospheric agents, which implies a greater change of level of land and sea than the 2,000 or 3,000 feet above mentioned. If it were a question of simple elevation, it would amount to 12,000 or 15,000 feet higher than at present along the border of the continent. This great elevation, however, may have been much reduced by an unequal bending down of the continental slope, or indeed to some extent by a shifting of the oceanic waters. Then also arises the question, What became of the waters, and also what were the causes of these great continental movements, about which we know nothing? The problem thus becomes so complex that the writer has to confine himself to the study of the resemblances above mentioned. While the features along the Atlantic coast are repeated on the eastern side of that basin and elsewhere, the author could not possibly imply a general drainage of the basins, but rather that there have been alternations, whereby great regions have been elevated while others have been depressed, as, for instance, the West Indian islands alternating in altitude with the lands of Central America. We know that in the epeirogenic movements the changes of level are unequal, with the rate of elevation or subsidence increasing or diminishing, and from the writer's observations such rates increase on approaching mountain regions and diminish in the direction of the plains. This, extended to the great continental slopes, would favor the theory of their having been abnormally bent downward; consequently the land may not necessarily have stood 12,000 or 15,000 feet higher than now, although the bottom of the slopes had been emerged to that extent. Still the land stood very much higher than at present, probably sufficient to give rise to glacial conditions in the north.

While the amphitheaters, coves, or canyons indenting the edge of the submerged continental shelf are known to have a breadth increasing

from 3 miles (that of the Hudson) to 5 or 10 miles, or where farther down the continental slopes the valleys open into embayments of 20 or 30 miles, even that breadth is no greater than can be seen in the lower reaches of many land valleys. It is seldom that we are able to restrict the channels to their actual breadth for want of closer soundings, such as have been made along a part of the Hudson valley and along the submerged extension of the Congo river, the last of which I may be permitted to refer to as a most detailed piece of work in revealing buried channels. Here the soundings were taken so as to obtain contours at given depths apart, which were often not more than half a mile. Thus Mr J. Y. Buchanan * found the depth of the river to be 900 feet at a dis-



Isobathic Contours from soundings on the Admiralty Chart No 604.

FIGURE 1.—*Submarine Channel of the Congo River.*

Soundings in fathoms.

tance of 20 miles above its mouth, where there is an obstructing bar. At 35 miles from the coast line the canyon has a breadth of 6 miles and a depth of 3,000 feet below the submerged plateau. The 6,000-foot contour of the continental slope recedes landward for 30 miles at this point. Beyond, Professor Edward Hull finds that the valley at over 7,500 feet indents the great slope for 20 miles landward. On account of the excellency of this study, the map of the Congo channel is here reproduced.

Again, outside the region of the present study we find many illustrations better revealing the form of the valleys than those so far deter-

*Chart taken from "The suboceanic river valleys of the west African continent," etcetera, by Professor E. Hull. Trans. Victoria Institute, vol. xxxii, 1900. Also see Mr Buchanan's paper, Scottish Geog. Mag., vol. iii, 1887, pp. 217–238.

mined off our own coast. Thus on the chart between Jamaica and Central America there is a submarine plateau rising almost to sealevel, and in the accompanying illustration this may be seen in places incised by narrow channels, and, again, these, uniting from the opposite side of the submarine plain, divide it into separated banks or islands. These suggest, not merely a moderate elevation that formerly obtained, but also one of considerable amount, as, for example, those seen between Jamaica and Haiti, where the lower plateaus are indented by the 500 and 1,000 fathom contours.

One other point may be again referred to here—the gradients of the valleys down the continental slope. As the great descent is usually

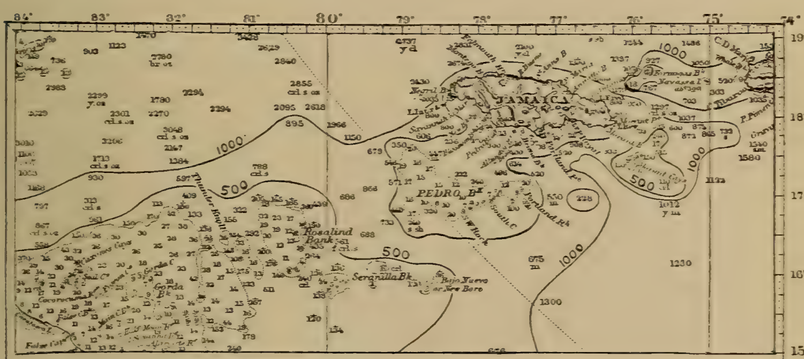


FIGURE 2.—*Chart of Area between Haiti and Central America.*

Showing dissection of banks by narrow channels and valleys. Soundings in fathoms.

restricted to a comparatively short distance, the mean declivity of the valleys at first seems too great for comparison with those of the land, but, as we have already found, these are often characterized by abrupt steps, with more gentle gradients between, similar to the valleys descending from the high plateaus of Mexico and Central America or the tributaries of the Colorado canyon, which descend 3,000 feet in perhaps 10 miles. But, in order to reveal their true character, the soundings must be made close together for this purpose, as the mean slope gives us no information whatever; and so, for the present, the best the writer can do is to compare them with land valleys from high plateaus, which is justified in the study of the Floridian channel, which descends by long stretches, with gradients of a foot or less per mile, as small as that of the Mississippi, succeeded by precipitous steps like those from one submarine plateau to a lower.

To cover all the questions raised would far exceed the limits of this

paper, the object of which is to record the facts given, with a brief statement of the writer's explanation of these most interesting phenomena.

Summary and Conclusions

The coastal plains of the continent pass under the sea and extend for 20 miles off cape Hatteras, 70 to 80 miles off New Jersey and beyond, again somewhat reduced in breadth, but widening out to 300 miles southeast of Newfoundland, now forming the banks. Their gradient is almost unappreciable to a depth of 200 to 250 feet. In front of this margin is a lower terrace, extending for a few miles to a depth of 400 to 450 feet, beyond which the great continental slope begins. The terrace form is best shown on the Newfoundland banks, while the outer slope of the submerged plain is wanting off cape Hatteras. These plains are often incised with channels to depths of 100 to 200 feet or more, suggesting their more reccent elevation of 400 to 600 feet. Adjacent to the coast the channels are apt to be filled by delta deposits or by sands drifted by the currents during the slight changes of level of the land, in the same way that great sandbars, with lagoons behind them, have been formed along the Atlantic coast.

The Laurentian valley has a breadth of 30 to 60 miles, with a depth of 1,200 to 1,500 feet below the submerged continental plain. The Fundian valley and its tributaries have a somewhat less depth. The drowned lands in this region have the same general physical characteristics as the coastal plain farther south, except the irregularities due to drift and to the less prevalent coastal sands, so that the Tertiary deposits of the banks may be seen, traversed by river-like channels.

Although the Laurentian and Fundian valleys are of greater age, they were kept open or reopened in the late geological epoch when channels were made in Tertiary beds. They were a feature when the land stood about 2,000 feet above the present altitude and not much higher, else the deeper outer valleys would have receded farther landward; but the margin of the continental shelf is everywhere incised in continuation of the channels of existing rivers by coves, amphitheaters, or gulfs to depths of 2,000 to 3,000 feet, where the submergence of the plains is from 250 to 400 feet or a little more. These features are the same as those on the border of the Mexican tableland. The submarine canyons widen into valleys, more or less apparent, to the foot of the great continental slope. So noticeable are they in contouring the soundings that they force our attention to them, although the data is not as full as could be desired. In descending the slope there are apparently lower gulfs or

stretches with exaggerated gradients, separated by reaches of only gentle decline, forming steps. Occasionally outlying portions of the continental slope seem to become terraces or more deeply submerged plains of slight inclination, with promontories extending from them, overlooking the deep valleys; as, for example, the valley of the Chesapeake passes over two precipitous declivities of 2,000 to 3,000 feet each, and it is traceable for upward of 60 miles from the edge of the continental shelf, where it enters an embayment at the foot of the continental slope. The coves or gulfs of the Delawarean, Hudsonian, Fundian, Cansoan, and Laurentian valleys are each characterized by the deep steps just noted. So also there are amphitheaters indenting the edge of the coastal plain submerged far away from present shores. These valleys traceable down the continental slope are in size no greater than those of existing rivers. The phenomena of all these strikingly repeat themselves. The valleys seem quite independent of mountain folds and are more or less at right angles to the orographic system, though the rivers entering them may either cut across the mountains or occupy depressions parallel with them.

The incisions in the floor of Baffin bay and Davis straits are magnificent examples of coves, canyons, and valleys indenting the land masses, though they are now sunken to form fiords. The Greenland-Iceland-Shetland ridge, which comes near the surface of the sea, is also incised by similar valleys trending in opposite directions toward both the Arctic and Atlantic basins, so much so that it would not be a bold prediction to expect to find submarine river valleys descending the North Atlantic plateau if close soundings were made. Even these deep gulfs have been discovered far north, off Spitzbergen. Thus, while there are local variations, the exact phenomena of land features are found from tropical to arctic zones and from regions of volcanoes to those of glaciers, whose forces are subordinate to atmospheric action, which appears to have stamped itself upon the great submarine slopes of the continent.

Passing over the old topography of the continent to its margin, it appears that the features described are newer than the remnants of the Miocene accumulation of the coastal plains; but the period when the broad valleys were deepened into canyons was subsequent to the Lafayette epoch, and while of shorter duration than the ages which gave rise to the general features, was sufficiently long to form the amphitheaters, canyons, and valleys which we have described. These last appear to belong to the general period of glacial deposits, and suggest a recent great elevation of the land, following out the teachings of Lyell, that where now the sea is the land once stood. The minor inter or post

Glacial elevation did not exceed from 200 to 450 feet above the present level.

Appendix

As Mr Lindenkohl, of the Coast Survey, had previously made the studies of the submarine valleys along the coast, I submitted this paper to his consideration, in reply to which I received the following communication, with permission to use it, and as it brings out one or two points, I take the liberty of adding it to the foregoing paper:

"Washington, D. C., *December 26, 1902.*

"Dear Sir: I have perused with great interest your paper on 'Submarine valleys," etcetera. . . . Your statements accord very well with my recollections, and your conclusions seemed to have been reached by sound logical reasoning. . . . Are there no indications of a submerged Connecticut river, a river in which Professor Dana was greatly interested? Some years ago I traced a river channel from the entrance of Narragansett bay to two-thirds the way from Gay head to Block island, where a terminal moraine is incised by a deep gorge (216 feet). This channel disappears in a bar of about 165 feet below sealevel. Allowing 15 feet for effective depth of bar, these figures indicate the subsidence of about 150 feet since the Glacial period. There is a similar submerged channel between Block island and Montauk point.

"The channel of the Narragansettan river passes through an inner or later moraine, stretching to the northern shore of Long island. A branch of the Narragansettan river enters the sound. I have no doubt that more indications of submerged channels will be found wherever they are not obliterated by glacial drift or other sediments when a careful search shall have been made. The fact of the existence of similar channels from the European side of the Atlantic appears to me to favor the theory of an accumulation of water in the northern part of the ocean" (meaning a change of ocean level by transference of the waters, as shown in the subsequent letter) "rather than the subsidence of the land, but I assume that your close investigations into the geological structure of the Antilles has enenabled you to correctly explain the physiographical features of the adjacent sea bottom.

"Yours very truly, A. Lindenkohl."

So far as the information is before me, it seems that the Connecticut river was a tributary to that from Narragansett bay, as I know of no buried channel across Long island, nor is there sufficient indentation or corresponding cove in the edge of the continental shore, as is the case in front of Narragansett bay.

With regard to the causes of change of level of land and sea, I do not exclude Mr Lindenkohl's suggestions that part of the change may have been due to the movements of the oceanic waters, as there are many observations which sustain the hypothesis; yet at other points the deformation of the land is independent of the ocean level and in part has given rise to the changes.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 14, PP. 227-268, PLS. 21-31 JULY 10, 1903

CLASTIC DIKES

BY J. F. NEWSOM

(Read before the Society January 1, 1903)

CONTENTS

INTRODUCTION

Classic dikes have been of interest and have been regarded somewhat as anomalies ever since the origin of igneous dikes became fixed in the minds of geologists. This fact is made apparent by a review of the literature concerning the dikes of sedimentary materials described in various parts of the world. Most of such dikes are small, and were they of igneous materials would scarcely call for remark.

The present paper describes a number of sandstone dikes in San Luis Obispo and Santa Cruz counties, California, to which the writer's attention was called by Dr J. C. Branner in 1901. The notes on which the paper is based were made by the writer in the summer of 1901 and the spring of 1902.

A paper, describing a number of the intrusions occurring in Santa Cruz county, was read and illustrated by lantern slides by Doctor Branner and

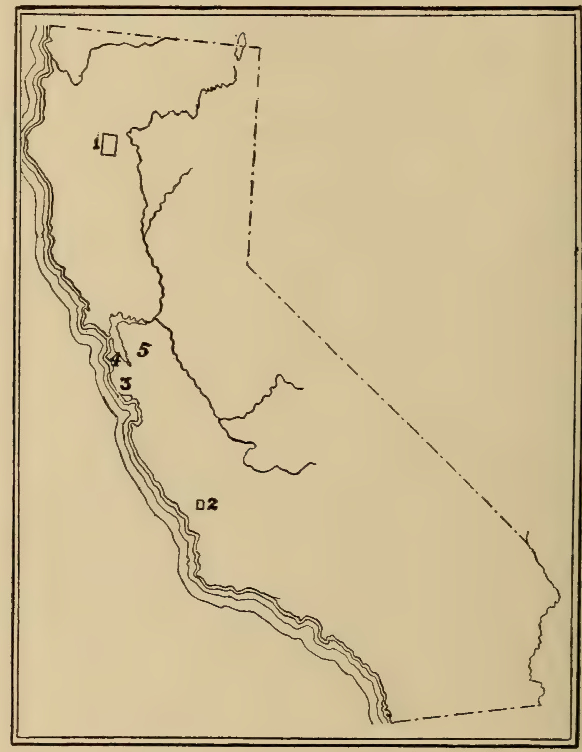


Figure 1.—*Skeleton Map of California.*

Showing areas in which sandstone dikes have been described. 1 is the area in which dikes have been described by Diller; 2 is the San Luis Obispo County region; 3 is the Santa Cruz region; 4 is the Stanford University locality; 5 is the Corral Hollow locality.

the present writer before the Geological Section of the American Association for the Advancement of Science at the Denver meeting in 1901.

The locations of the areas described, as well as those localities in California in which sandstone dikes have been formerly described by Diller and others, are shown on the accompanying skeleton map of California (figure 1).

In this paper the dikes of San Luis Obispo county will be taken up first; then those of Santa Cruz county and all other localities observed by the writer will be described and the conclusions concerning them considered. After this discussion a brief review and bibliography of the literature bearing on the subject of clastic dikes is given. While the bibliography may not be complete, it contains references to the papers on the subject that have come under the writer's notice while looking up the literature on clastic dikes.

Sandstone Dikes in San Luis Obispo County, California

LOCATION

In San Luis Obispo county sandstone dikes occur about one and one-half miles southwest of Asuncion, a station on the Southern Pacific railroad. They are exposed at intervals along Graves creek, in the Rancho del Encinal, for a distance of about one-half mile. The dike that is farthest upstream is about one mile above the ranch-house of the Rancho del Encinal.

GEOLOGIC RELATIONS

The rocks of the locality are Cretaceous sandstones, overlain by diatomaceous shales of Miocene age. Both the general relations of the strata and the manner in which the dikes cut the shales are shown in the accompanying plan and cross-section of the area (figure 2).

The underlying Cretaceous sandstones, where observed by the writer, are massive, rather fine grained, and of a brownish color. They lie to the west and south of the diatomaceous shales, and the shales in which the dikes occur dip away from the sandstone area.

The color of the sandstone and its texture where exposed 200 yards above the dikes on Graves creek are somewhat different from that of the sand composing the dike at 1, as well as the other dikes of the Asuncion region, which are for the most part composed of fine grained, hard gray sandstone. It is by no means certain, however, that the texture of the sandstone lying immediately below the dikes is not similar to that of the dikes. The color of the Cretaceous sandstone is evidently due to iron oxide, and it seems quite reasonable to suppose that this iron may have been removed by water circulating through the intruded sands prior to their firm cementation by calcium carbonate.

The diatomaceous shales which inclose the dikes are brittle and much jointed. They are light in weight; in color they vary from light gray

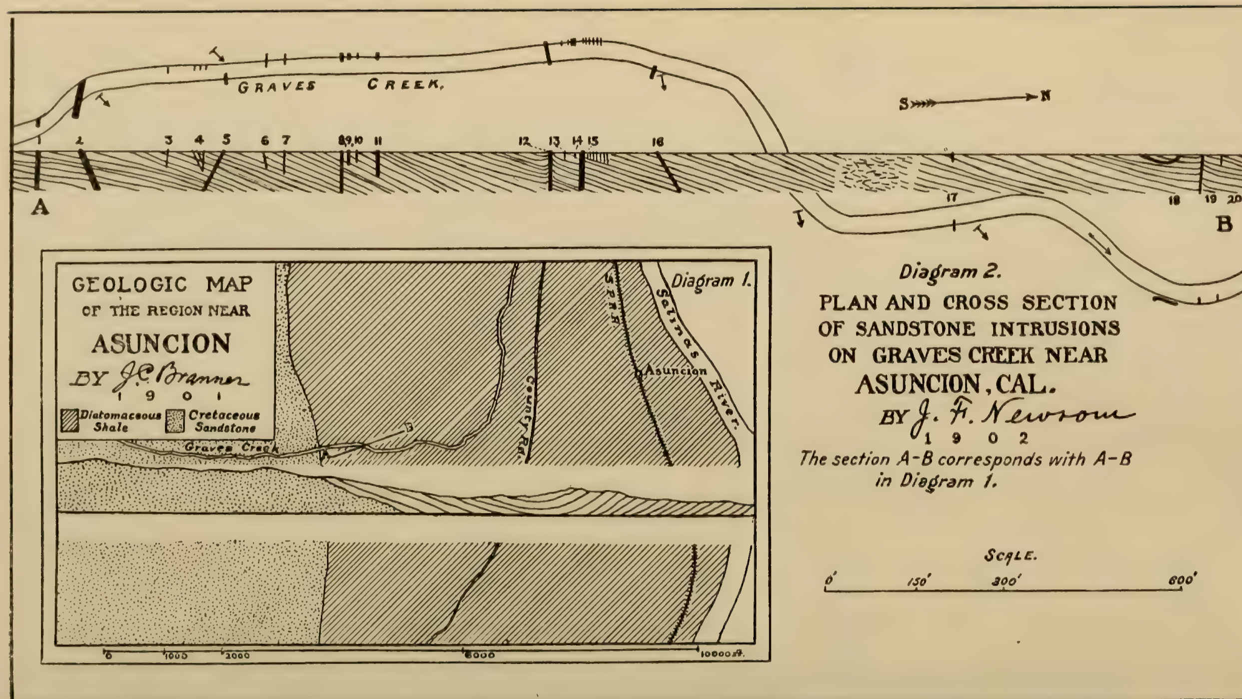


FIGURE 2.—*Relations of the Graves Creek Dikes.*

Diagram 1 is a map and cross-section of Graves creek, showing areal geology and structural relations near Graves creek and the location of the plan and section *A–B* shown in figure 2, diagram 2.

Diagram 2 is a plan and cross-section showing the relations of the dikes and the inclosing rocks on Graves creek, near Asuncion, California. Cretaceous sandstone crops out in the creek bed a few hundred feet south of dike 1, at the south end of the section. While no connection can be seen between dike 1 and this underlying sandstone, such a connection may exist.

to white. These shales are but slightly folded along Graves creek where the dikes occur, the recorded dips varying from 9 to 30 degrees.

CHARACTER OF THE DIKES

The dikes are composed of fine-grained sand, for the most part firmly cemented by calcium carbonate, while some of them contain a network of calcite veinlets. A fragment of a hard dike, when treated with cold HCl effervesces freely and soon crumbles to a mass of soft sand, owing to the complete removal of its cementing material.

Both the large and the small dikes are harder, with one or two exceptions, than the inclosing shales, and they therefore stand out above the shale where exposed in the creek bed and in the banks. This feature of their weathering is well shown in the figures of plates 21 and 22 and in figure 3.

The contacts between the sides of the dikes and the inclosing shales are sharply defined, and the inclosing walls are quite smooth. In many cases inclusions of the diatom shale occur in the sandstone of the intrusions. These intrusions are similar in appearance to the inclosing shales and doubtless were detached from the shales and mixed with the sand as the latter was being injected into the fissures where it is now found.

In thickness the dikes on Graves creek vary from mere veinlets, a fraction of an inch thick, to intrusions 10 feet thick. With one exception those observed stand at high angles, and in some cases they are vertical. In strike they do not vary greatly from an east and west direction.

The variations in dip and strike are indicated in the plan and cross-section shown in figure 2.

DESCRIPTION OF THE DIKES

In the following remarks the dikes will be referred to by the numbers which indicate their positions in figure 2. Those that are insignificant or of no especial interest are not described.

At 1, figure 2, is a dike of hard gray sandstone with an exposed thickness of 4 feet. Its entire thickness was not seen, owing to its being partially covered by creek sand. It stands in an almost vertical position and has a strike of south 84 degrees west, while the shale near by dips 27 degrees north 45 degrees east. This dike is near the base of the Miocene (diatomaceous) shale, which is underlain here by a coarse yellowish Cretaceous sandstone; the latter outcrops 600 feet up the creek from the dike.

At 2, 75 feet downstream from 1, is a 10-foot dike of fractured hard gray sandstone containing innumerable calcite veinlets. One of the walls of this dike shows a dip of 65 degrees north 6 degrees east. This intrusion crops out of the hill east of and 45 feet above the creek.

At 3, 150 feet below 2, is a dike varying in thickness from 2 to 6 inches and standing almost vertical. It has a strike of south 66 degrees west. The shales here dip 20 degrees north 56 degrees east.

At 4, immediately below 3, are three thin intrusions shown in figure 1, plate 21. In the picture the hammer leans against 2, the figure of the man is midway between 2 and 3, and at the right of the picture 4 is shown. These intrusions vary in dip from 55 to 90 degrees and in thickness they vary from 1 to 3 inches. They are much harder than the inclosing shales and stand up above the shale like the irregular edges of so many boards.

The dike indicated at 5 is 18 inches thick; it dips 70 degrees south 14 degrees east and cuts shale which dips 30 degrees north 35 degrees east. This intrusion, which contains inclusions of shale, is of hard gray sandstone and projects 18 or 20 inches above the shale, sand, and gravel in the creek bed.

Forty feet below 5, at 6, a 3½-inch dike dipping 80 degrees north 5 degrees west is exposed at the west side of the creek; it is of hard sandstone and stands out from 10 inches to 1 foot above the shale. This intrusion is slightly faulted. The faulting and the relations of the dike to the shale are shown in figure 2, plate 21.

At 8 is a 6-foot, vertical, hard, gray sandstone dike with many calcite veinlets; at 9, 4 feet below 8, is a 22-inch intrusion standing vertically and striking north 65 degrees east, and at 10, which is 4 feet below 9, is a 4-inch dike with shale inclusions. It is almost vertical and is parallel to 9. These dikes are exposed on the west side of the creek and outcrop for a distance of about 15 feet. Figure 1, plate 22, looking west, shows the relations of these intrusions to each other.

Thirty feet below 10 a 2½-foot dike is poorly exposed at 11.

At 12, 200 feet below 11, one of the most interesting of the Graves Creek dikes is exposed on both the east and west sides of the creek for a distance of about 35 feet. It is vertical, has a strike of north 70 degrees east, is composed of hard gray sandstone, and contains shale inclusions. The best exposure is in the east bank of the creek (figure 3). Here the intrusion is 2½ feet thick at the level of the creek bed. Six feet above the waterlevel it increases to a thickness of 5 feet.

While the shale both above and below on the creek has the ordinary low northeast dip, the beds adjacent to the dike are tilted up and dip away from the intrusion on either side at an angle of about 45 degrees.

FIGURE 1.—THREE DIKES AT 4
Strike of dikes is across that of enclosing shales

FIGURE 2.—DIKE AT 6
Relations of dike to adjacent shale and the slight lateral faulting is shown

DIKES ON GRAVES CREEK, NEAR ASUNCION, CALIFORNIA

FIGURE 1.—DIKES 8, 9, AND 10

FIGURE 2.—DIKES 14 AND 15

DIKES ON GRAVES CREEK, NEAR ASUNCION, CALIFORNIA

This tilting is local to this inclusion and must have been caused by the intrusion of the sand from below. These features of 12 are shown in figure 3.

At number 13, 30 feet below 12, is an 18-inch dike of hard sandstone, while 25 feet lower downstream, at 14, is a 1-inch dike which dips 60 degrees north 25 degrees west. This thin dike is very hard, and thin as it is, and standing directly across the stream, has resisted the action of the current and stands well up above the shales cut by it. Two feet downstream from 14 is a 2-foot dike (15) of much fractured hard sandstone containing shale inclusions. These two dikes (at 14 and 15) are shown in figure 2, plate 22, in which the hammer is near 14.

FIGURE 3.—*Dike exposed at 12.*

A 2½ to 5-foot sandstone dike showing the tilting of the shales at either side, due to the injection of the sand from below.

Immediately downstream from 15 is a 3-foot intrusion with many veinlets. On the downstream side of this dike there are several more stringers of sandstone, as indicated on the plan and cross-section at 15 in figure 2.

A 40-inch intrusion, containing shale inclusions and dipping 64 degrees north 10 degrees west, is exposed on the east side of the creek at 16, 150 feet below 15. A short distance downstream from this exposure is a thin

bed of sandstone in the shale, the dip of which is 13 degrees north 80 degrees east.

Six hundred feet below 16 a 2-inch intrusion (dike 17) is exposed on the east side of the creek, and 350 feet still farther downstream 18 is exposed.

The dike at 18 (figure 1, plate 23) is exposed for about 120 feet along the bluff at the east side of the creek. This intrusion is unlike those seen farther up the stream in two particulars—it lies at a low angle and is composed of very soft yellow sandstone. It is about 6 feet thick at the thickest part, and at the south end of the exposure (the right side of figure 1, plate 23) it seems to conform with the shale beds above and below it. Toward the north end of the exposure it cuts obliquely across the shale beds; it forks at one place and has shale between the two branches, as may be seen at the left side of the figure.

At 19, 75 feet downstream from 18, is a 2½-foot intrusion of soft sand, standing vertically and exposed in the bank at the east side of the creek. This intrusion is exposed for 4 or 5 feet above the waterlevel, and at its top contains many shale inclusions. Immediately above it the shale is much jointed and broken up, but it is not cut through by the sandstone. The shale beds dip away from both sides of the intrusion as though they had been forced up by the injection of the sandstone under high pressure from below, resembling 12 in this particular. These features of the structure can be seen in figure 2, plate 23.

At 20, which is 25 feet below 19, is a small soft sandstone intrusion, the top of which is exposed at the water's edge. No dikes were observed on Graves creek below this point.

SUMMARY OF THE GRAVES CREEK DIKES

Following is a summary of the principal features of the sandstone intrusions along Graves creek, and the conclusions regarding them:

1. The dikes occur near the axis of a low synclinal fold, where former conditions were probably favorable to great hydrostatic pressure.

2. With one exception, the dikes stand at angles varying from 60 to 90 degrees. In strike they vary from north 65 degrees east to south 85 degrees east; the strike of the shale varies from north 10 degrees west to north 55 degrees west. The angles formed by the strike of the dikes and that of the shales, where the latter were measured, vary from 50 to 90 degrees.

3. With three exceptions, the dikes are of hard gray sandstone. Some of them are intricately and irregularly jointed, and the joints often contain calcite veinlets. The cementing material in the hard dikes is calcite.

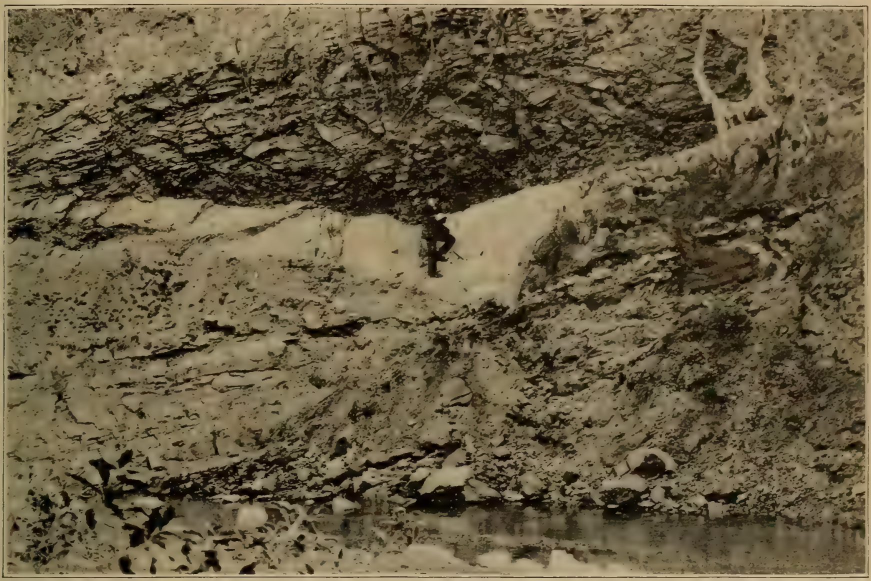


FIGURE 1.—DIKE 18

Dike is of soft yellow sandstone, in part conforming to shale beds (right side of figure) and in part cutting obliquely across these beds and dividing into two branches (left side of figure)

FIGURE 2.—DIKE 19

Shale beds dip away from both sides of the intrusion, which is directly under figure of man

DIKES ON GRAVES CREEK

4. At two of the dikes the beds of the shale walls have been bent upward, suggesting that the sand was forced in from below, under sufficient pressure to cause the upturning of the shale beds.

5. No bituminous odor is apparent in any of the Graves creek dikes.

CONCLUSIONS AS TO ORIGIN OF THE GRAVES CREEK DIKES

A study of the dikes along Graves creek leads to the conclusion that the sand of these dikes was injected from below by hydrostatic pressure.

This conclusion is borne out by the following facts :

1. The only sandstone of the immediate locality (with the exception of the insignificant bed noted on page 234) is that of the underlying beds.

Whether the dikes were derived from the underlying Cretaceous sands or from sands which may be interbedded with the Miocene shales below the intrusions (as seems more probable) is not known.

2. The shales at the sides of dikes 12 and 19 could have been turned upward only by the drag of sands intruded from below, or by the injected sands forcing the shales apart along a fissure. The edges of the shale could scarcely have been turned upward by sands being injected or falling in from above.

3. At dike 19 the sandstone is overlain by broken shales as though the sand had not been forced completely through the shales. This, taken in connection with the upturned edges of the shale in the walls of the sand-filled fissure, points strongly to the conclusion that the sand was injected from below.

The writer is of the opinion that the soft sands were forced up along joint planes, and that the walls of the fissures were more or less gradually pushed apart by the sands in much the same way as igneous injections might do. There seems no reason for supposing that an open fissure was produced ready to receive the sands, and the contortions of the shale beds at 12 and 19 would oppose such a view.

After their injection into the shales, the sands were firmly cemented by calcium carbonate precipitated from circulating water.

Sandstone Dikes near Santa Cruz, California

LOCATION

The sandstone intrusions of the Santa Cruz region are exposed along and near the sea-cliff from 8 to 13 miles west, and at the bituminous rock quarries 5½ miles northwest of Santa Cruz. These two localities are about 3 miles apart. The general location of this region is shown

in figure 1, while the relations of the dikes along the coast to those at the asphalt quarries are shown in figure 4.

GEOLOGIC RELATIONS OF THE DISTRICT

The geologic relations are comparatively simple in the region near Santa Cruz, in which the sandstone intrusions occur. The oldest rocks in the district are the granites which form the core, and the eastern crest

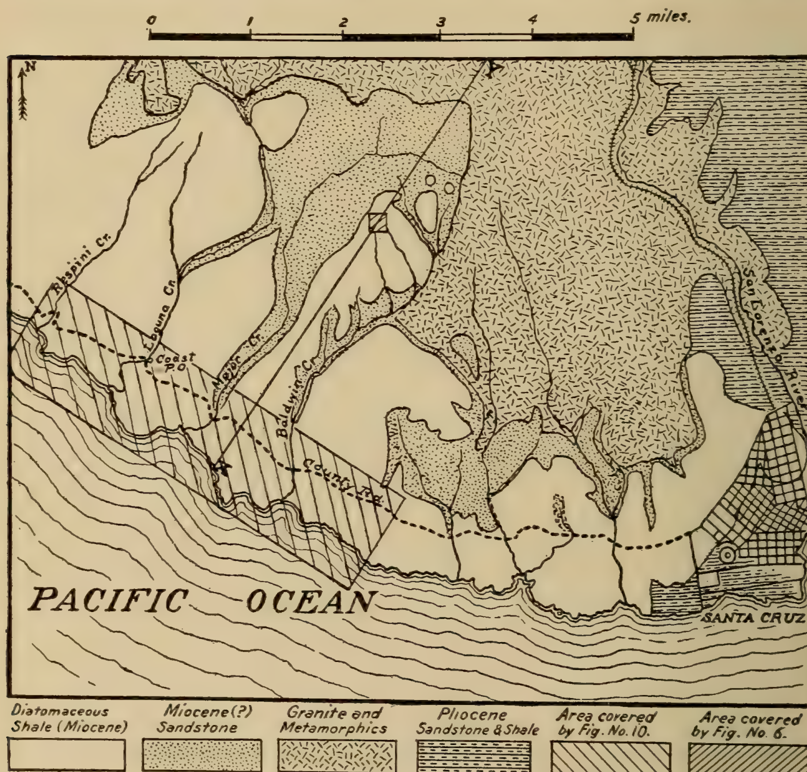


FIGURE 4.—*Geologic Map of the Santa Cruz Dike Region.*

The sandstone intrusions occur west and northwest of Santa Cruz, California.

of Ben Lomond mountain. Resting on the granite in some places are schists, with overlying patches of metamorphosed limestones and quartzites; at others the later sedimentaries, supposed to be of Miocene age, lie directly upon the Ben Lomond granite.

The east face of Ben Lomond mountain forms an abrupt escarpment, but to the west and south the mountain slopes gradually to the sea, and on three sides it is flanked by sandstones and diatomaceous shales of

supposed Miocene age. Near the base of this sedimentay series the sandstone beds are intercalated with the shales, while beneath the shales and lying between them and the granites or metamorphic rocks, as the case may be, is a more or less continuous sandstone bed, often as much as 200 feet thick. This basal sandstone, as well as the sandstones that are interbedded with the shales, is often slightly bituminized, and at some places it is highly bituminized.

The sandstones and shales have general westward and southwestward dips of from 10 to 20 degrees. Thus the shales and sandstones in the region where the dikes occur form the eastern side of a monocline or of a broad syncline, the axis of which is beneath the Pacific ocean.

DIKES AT THE ASPHALT ROCK QUARRIES

The asphalt* quarries, where some of the dikes described below occur, are 3 miles from the coast and have an elevation of 1,000 feet above tide

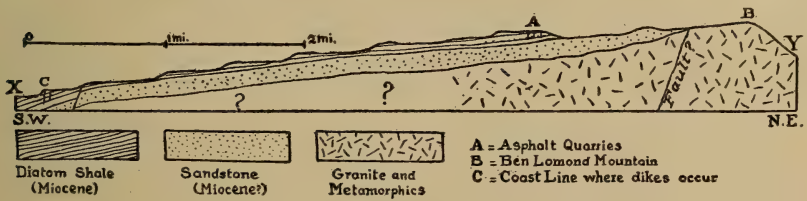


FIGURE 5.—*Cross-section along the Line X–Y, Figure 4.*

Showing the geologic structure and the sea terraces.

level. The dikes to the west are along the coast line and in the sea-cliff, which is from 50 to 75 feet high. The intrusions along the coast line, as well as those at the asphalt quarries, cut diatomaceous shales.

Between the asphalt quarries and the coast are a number of beautifully cut sea terraces. The character of these terraces is indicated on the accompanying sketch map, figure 10, while the general geologic relations of the region are shown in figure 4, and the cross-section, figure 5. The bituminized sandstones which have supplied the material for many of the dikes occur near the bottom of the shale series.

The sandstone intrusions at the asphalt quarries of the City Street Improvement Company (see figures 4 and 6), in the Santa Cruz district, pass from the bituminized sand beds into the shale beds above. The sandstones are so heavily charged with bitumen that the fragments in piles of the broken rock soon become firmly cemented. In some cases

* The terms asphalt quarries used here and on the succeeding pages relative to the Santa Cruz region applies to quarries where bituminized sandstone is obtained, and not to pure asphaltum deposits. No large deposits of pure asphaltum are known to occur in the region about Santa Cruz, California.

bitumen exudes from the sands. The rock, which is brittle to a sharp blow, is plastic under a gentle or even pressure. Only a few of the more interesting of the many intrusions at the asphalt quarries are described and figured below. The locations of the quarries and of the dikes that are figured from these are shown in figure 6, and at A, figure 5.

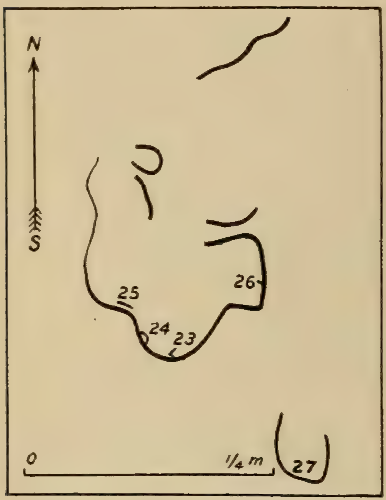


FIGURE 6.—*Diagram of the Asphalt Quarries.*

These quarries of the City Street Improvement Company are five and one-half miles northwest of Santa Cruz. The heavy black lines show the quarries. The numbers refer to the dikes that are described and figured below.

In thickness the dikes at the quarries vary from mere films along joint planes to intruded masses fully 10 feet thick. Some of the thinnest of the intrusions composed of bituminized sands follow joint planes for 30 or 40 feet from the parent sandstone bed below. It is remarkable to what distances and into what thin cracks these sands have in some cases been forced.

In some instances the dikes branch and the branches again coalesce (see figures 7, 8, and 9). In this respect they resemble dikes of igneous rock and they have doubtless been formed in much the same way, except that intense heat has not been necessary to give plasticity to the injected material.

At the east side of the main or Point quarry the bituminous sandstone and the overlying shales are faulted, the down throw of about ten feet being on the east. Along the fractured zone and above the sandstone there are large masses of intruded sandstone with shale inclusions.

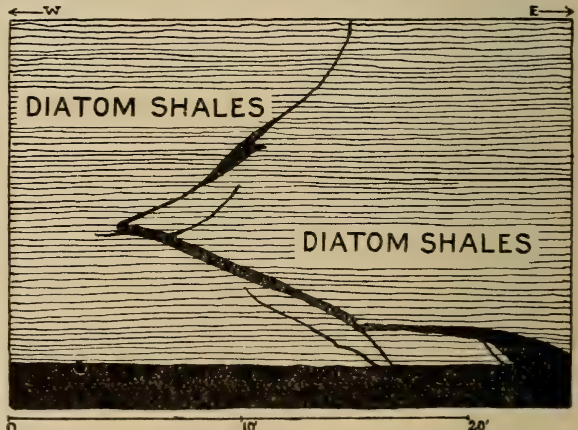


FIGURE 7.—*Bituminous Sandstone Dike at Point Quarry.*

This picture was taken in August, 1901. The top of the main bituminous sandstone bed from which the dike is derived is shown in black at the bottom of the picture.

Near the middle of the south side of the Point quarry is a thin dike which branches and cuts the overlying shales in an interesting manner. Its base is connected with the underlying sandstone from which it is evidently derived; in thickness it varies from a thread to a thickness of about a foot, and it penetrates the shale for 30 feet.

In figure 7 a portion of this dike is represented, though the top of it is not shown.

In figure 8 a dike at the west side of Point quarry is shown. At this place the lower layers of the overlying shale have been broken down and the sands have been pushed up behind them. The derivation of this intrusion is obvious from its relations to the overlying shales and its connection with the underlying bituminous sands.

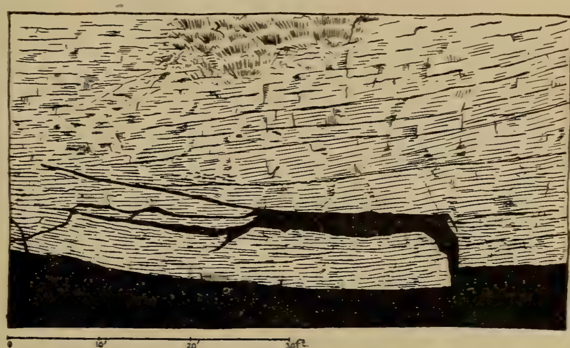


FIGURE 8.—*Intrusion of Bituminous Sand in Diatom Shales.*

The view is at the west side of the Point quarry (24, figure 6) of the City Street Improvement Company, near Santa Cruz, California.

At the north end of Point quarry (25, figure 6) a large intrusion cuts the shales at angles varying from 0 to 90 degrees. The main part of this dike, X–Y, is about 6 feet thick. The top of the vertical portion, A, is about 4 feet thick. The dike reaches the surface at A, and its bituminous matter has been leached out, leaving more or less barren sand and debris in the fissure at that place. In going down from A to Y, the sand becomes more and more highly bituminized. The main body of the dike, X–Y, is quite highly charged with bitumen.

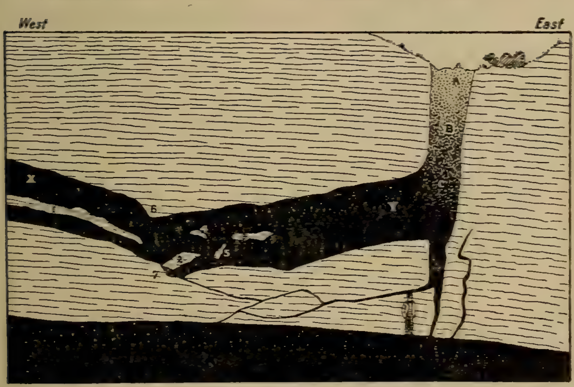


FIGURE 9.—*Dike 25, at North End of Point Quarry.*

At 1, 2, 3, 4, 5 in figure 9 are inclusions of diatomaceous shale in the sandstone, while at 6–7 the dike has apparently been slightly faulted.

FIGURE 10.—*Map and Cross-sections.*

Showing the relations of the sandstone intrusions and the adjacent rocks on the California coast west of Santa Cruz.

The main bituminous bed of this locality, and the one from which the intrusion at 25 was probably derived, is shown in black at the bottom of the picture.

At the Side Hill quarry (26, figure 6) is a fine exposure of an intrusion which cuts some 30 feet of diatomaceous shale overlying the bituminous sand bed. The dike is connected with the underlying bituminous sand bed, as shown in figure 1, plate 24; it varies in thickness from 2½ feet near its top, 30 feet above the parent sand, to 6 feet in its thickest part, a few feet from the place where it unites with the underlying sandstone.

At Rattlesnake quarry (27, figure 6) the overlying shales are greatly fractured, and along the fractures are many bituminous sand intrusions, which cut the shales at all angles from 0 degrees to 65 degrees, and are in many cases directly connected with the underlying sandstone. In thickness the intrusions vary from mere stringers to a 15-foot, jumbled mass of bituminized sand with included shale fragments, which extends 8 feet up into the shales.

FIGURE 1.—INTRUSION OF BITUMINOUS SANDSTONE (26)

Asphalt rock quarries northeast of Santa Cruz, California

FIGURE 2.—WEST END OF DIKE 30

Dike is harder than the diatom shales and stands out above them

BITUMINOUS SANDSTONE DIKE AND WEST END OF DIKE 30

SUMMARY AND CONCLUSIONS AS TO DIKES AT ASPHALT ROCK QUARRIES

In summing up the conditions at the asphalt quarries the following are the most noteworthy points:

1. The dikes vary in thickness from mere films along joint planes to intruded masses several feet thick.

2. Many of the intrusions are connected with the underlying bituminized sand beds and under such conditions that there can be no doubt but that they were derived from these underlying beds. All of the dikes of this region were apparently injected from below.

3. The jumbled masses of bituminized sandstone and shale are exactly such as might be expected from the slow intrusion of a plastic substance into highly fractured zones in such rocks as the diatom shales.

It seems to the writer that the large as well as the small masses, or dikes, of bituminized sandstones which intersect the overlying shale beds at varying angles in the Santa Cruz region owe their present position to fracturing in the shale beds and to the injection of the sands into those fractures, probably at a time when the sands were in a much more plastic condition than they are at present. In view of the extremely large intrusions along the coast (described below), it does not seem unreasonable to suppose that entire beds of bituminized and plastic sands might be squeezed into the overlying shales. Thus a deposit might retain its original simple bedded position at one place, and at another turn up and intersect the overlying beds as a true dike.

Dikes along the Coast West of Santa Cruz

LOCATION

With the exception of No. 57, the dikes described below outcrop along 3½ miles of coast line, reaching from the mouth of Baldwin creek, 5 miles west of Santa Cruz, to the mouth of Respini creek, 8 miles west of that city. Number 57 is at the mouth of Scott creek, 13 miles west of Santa Cruz.

The coast in this region is beautifully terraced. The character of the topography is shown by figure 10. The structure of the region is shown by figure 5 and cross-sections *AB* and *CD*, figure 10. In section *AB* a fault with the downthrow on the west side is shown, while the dikes whose locations are shown and numbered on the coast line are shown in projection on section *CD*. The dips indicated along the coast line are those of the diatom shales which are cut by the dikes.

Along the eastern half of the coast line shown in the figure there are occasional thin bituminous sandstone beds interbedded with the shales.

Except in one or two cases noted below, no connection is apparent between these interbedded sandstones and the intrusions, and the writer believes that most of the intrusions along the coast were derived, not from the thin sandstone beds exposed in the sea cliff, but from the sandstone which underlies the shales of the entire portion of the coast shown in figure 10.

FIGURE 11.—*Dike 29, West of Santa Cruz, California.*

An intrusion of hard sandstone from 3 to 6 inches thick, cutting diatom shales.

DESCRIPTION OF DIKES ALONG THE COAST

The dikes will be mentioned in their order and particular attention will be called to the more interesting ones, beginning with 28 at the right (southeast) end of section *CD*, figure 10.

At 28, figure 10, a three-inch intrusion of fine, bituminized sandstone cuts the diatom shale to the top of the sea cliff, a height of about 30 feet.

Eight hundred feet southeast of the mouth of Baldwin creek, at 29, a 3 to 6 inch dike of hard, brown, rather fine grained sandstone is exposed with a dip of 80 degrees north, 75 degrees west. It cuts the shale to the top of the cliff, and, owing to its hardness, projects several feet from the side of the cliff at one place, as shown in figure 11. A freshly broken piece of this sandstone gave no odor of bitumen.

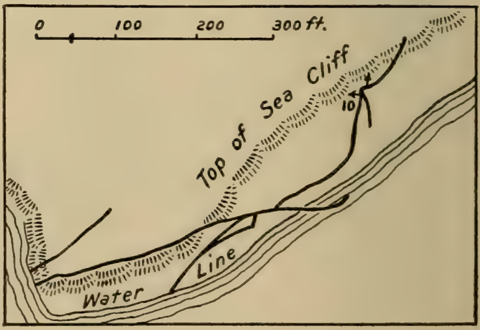


FIGURE 12.—*Plan of Dike 30.*

This dike is west of the mouth of Baldwin creek.

An interesting intrusion of the Santa Cruz region is that of dike 30, a few hundred feet west of the mouth of Baldwin creek, and

EAST END OF DIKE 30

Dike is exposed at low tide and its branches shown

shown in figure 2, plate 24, and in plate 25, and a plan of which is shown in figure 12.

The dike shown in figure 2, piate 24, and in plate 25, varies in thickness from 2 inches to a foot, and is composed of fine sand highly bituminized in places. It is harder than the shales about it and consequently stands above them on the beach.

The intrusion branches several times, as shown in figure 12 and plate 25; its dip varies from 10 to 90 degrees, and its strike is also variable. At its western end, dike 30 shows lateral faulting of 20 inches. The shales at this locality dip 5 degrees south, 15 degrees west.

At 31 there is a veinlet of bituminized sand from one-half inch to one inch thick, standing nearly vertical and having a strike of north 50 degrees east. The dike at 31*a* is 3 inches thick, vertical, and has a strike of north 25 degrees east. At 32 the dike is 8 inches thick, vertical, and strikes north 15 degrees east. At 33, veinlets from one half inch to one inch thick are exposed for 50 feet along the top of the wave-washed shale bench. These minute dikes are of bituminized sand, and have a strike of north 55 degrees east.

At 34 there are two small bituminized intrusions dipping 45 degrees north, 45 degrees west. They vary in thickness from one-fourth inch to six inches, becoming thinner and finally disappearing as they approach the top of the sea cliff, which is about forty feet high. The shale here dips 12 degrees south, 5 degrees east.

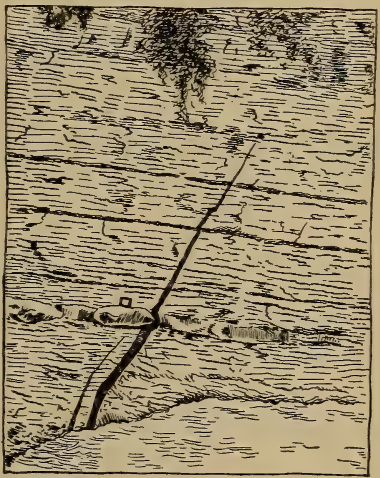


FIGURE 13.—*Bituminized Sandstone Dikes.*

At 34, figure 10, the mouth of Baldwin creek. Note the influence of the concretion upon the intrusion.

At the point southeast of the mouth of Majors creek, at 35, is a dike of much broken bituminized sandstone along a fault, having a downthrow of 4 feet on the east side. There are a number of very small dikes of bituminous sand along joints in the shales at this place. Half way to the top of the cliff, which is 65 feet high, is a thin bed of bituminous sand with which some of the dikes are connected and from which the dikes below have been derived, the injection of sand having been downward.

Immediately northwest of the mouth of Majors creek is a mass of bituminized sandstone interbedded with the shales. Whether this is a bed originally deposited in this position or is an intruded mass is not

known. The top of the mass conforms with the overlying shale, but its bottom is very irregular, expanding down in one place to a mass about 7 feet thick, beneath which the shale beds bend very slightly, forming a local synclinal fold. From the lower side of this mass there are branches which either rejoin the parent mass or thin out and disappear in the underlying shale. Figure 14 shows the conditions at this point.

At 37 a number of very thin bituminous sand dikes are exposed on the wave-washed sea cliff. They range in thickness from ¼ inch to 1½ inches. They branch and coalesce; their strike is north 15 degrees east.

Fifteen hundred feet northwest of the mouth of Majors creek, dike 38 outcrops (figure 1, plate 26.) This intrusion is exposed on the wave-washed shale bench for 150 feet and is from 6 inches to more than a foot thick. It is of hard, dark gray, fine grained sandstone. It is almost vertical and reaches to the top of the sea cliff, and owing to its hardness projects from the surrounding shales. The sandstone is much fractured and contains great numbers of false veinlets which are harder than the rest of the dikes. Many of these apparent veinlets are composed of sand, the grains of which have been cemented by calcium carbonate. They have probably been formed by lime-bearing water passing along fractures and depositing its lime in the sand on either side. While the sand has the dark color of the bituminized dikes of this locality, it is not charged with bitumen where exposed.

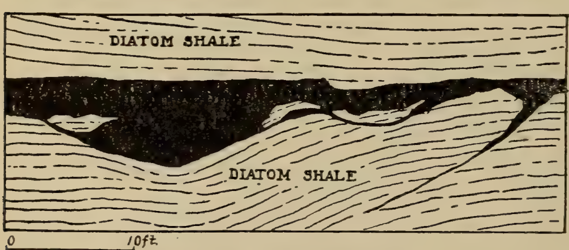


Figure 14.—*Mass of Bituminous Sandstone.*

This sandstone conforms in part to the shale beds near the mouth of Majors creek.

At 39, just south of the mouth of Laguna creek, a group of small, branching, highly bituminized dikes is exposed. These intrusions are faulted laterally near the top of the sea cliff, which is about 40 feet high. In thickness they vary from a fraction of an inch to 10 inches; notwithstanding their small thickness they contain many inclusions of diatom shale.

The manner in which these intrusions send off branches which reunite, or thin out to mere films and disappear, is shown in figure 1, plate 28. In hardness they do not vary greatly from the adjacent shales.

At 40, just west of the mouth of Laguna creek, is a 10-inch dike of soft sandstone. This intrusion offers an easy point of attack for the

FIGURE 1.—DIKE 38, NEAR MOUTH OF MAJORS CREEK

Fractured nature of intrusion and lateral fault at top are shown

FIGURE 2.—DIKE 41, NORTHWEST OF MOUTH OF LAGUNA CREEK

This locality is 7 miles west of Santa Cruz. View taken looking north

DIKES 38 AND 41

DIKE 41

This dike is west of the mouth of Laguna creek, Santa Cruz region

waves, which have cut it back 20 or 30 feet into the shale, forming a trench 5 or 6 feet across.

A short distance west of 40 at 41 is an intrusion of soft sandstone, brown at the top and yellowish green with peculiar diagonal, slightly faulted bands at the bottom. It is 6 feet thick at the bottom, 8 feet thick at the top, and reaches to the top of the cliff, which is only 18 feet high at this place. This intrusion is softer than the adjacent shales, and since it is in an exposed position the waves have worn it back through the shales for a distance of 40 feet, leaving an open trench. The surfaces of the sandstone and the shales where these come in contact are smooth and sharply defined.

The diagonal banding is indistinctly shown in the lower part of the dike in plate 27. The dark bands that pass across from the lower right hand corner upward and to the left are slightly bituminized. These bands are from 1 inch to 2 inches thick, from 4 to 6 inches apart, and are themselves broken by a series of small faults. The fault planes cut the bands at right angles and run off at angles of about 45 degrees to the hanging wall of the dike.

The lower half of the intrusion is slightly bituminized, especially along the diagonal bands, while the upper part is free from bitumen, possibly because it has been more weathered than the lower part.

Immediately west of 41 is a two-foot intrusion of soft, slightly bituminized gray sandstone which extends to the top of the bank. It contains shale inclusions and bands of sand that are more highly bituminized than the mass of the dike.

Figure 2, plate 26, shows the way in which the waves have cut the sand of this intrusion out from the shale which inclosed it. The shale here has a dip of from 12 to 20 degrees to the west. The intrusion is vertical and trends north 25 degrees east.

At 43 are a number of thin vertical stringers along a fractured zone, cutting from the bottom to the top of the sea cliff, which is about 50 feet high at this place. At 44, 45, 46, and 47 are small intrusions of soft, brown, fine grained sandstone, dipping about 50 degrees south, 65 degrees east.

At 48 is a vertical intrusion made up of two more or less lens-shaped parallel parts, which are united a little less than half of the way to the top of the exposure. The lenses, which vary in thickness from 1 to 10 inches, thin down and disappear before the top of the cliff is reached. This dike is composed of soft, gray, unbituminized sand and contains inclusions of shale. Figure 15 is a diagram of this dike.

At 49, in a cove just northwest of 48, is an intrusion of soft, yellowish gray and brown sandstone. The sand mass is exposed for 225 feet along

the bottom of the sea cliff, which is about 50 feet high. At its east end the mass cuts the shales to the top of the cliff in a chimney-shaped mass 40 feet across. Throughout this mass of soft sand are irregular wavy bands indicating flow structure. The peculiar wavy banded structure is shown in figure 16, which is from a photograph of the eastern end of the mass, showing its thickest part and also the chimney-like portion.

The diatom shale immediately east of the dike dips 15 degrees south, 75 degrees west, while that at the west end of the mass dips 10 degrees south, 15 degrees east.

The sandstone of this intrusion is practically free from the odor of bitumen. The line of contact between the adjacent overlying shale and the sand at the west end of the exposure is irregular. Intrusions of shale occur in the sand mass near the west end of the exposure.

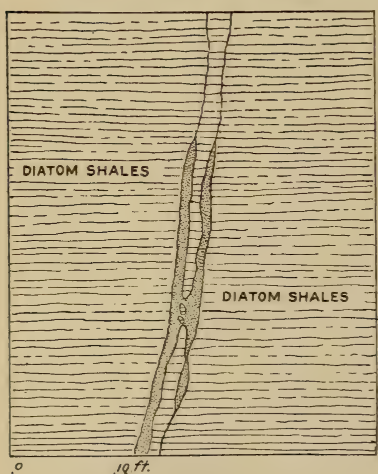


FIGURE 15.—*Diagram of Dike at 48.*

At 50 is a dike of soft gray sand varying in thickness from 10 inches to 2 feet. This intrusion is exposed for a hundred feet near the bottom of the sea cliff. At its two ends it cuts the shale beds at angles varying from 10 to 30 degrees, while at its middle it conforms to the shale beds. This dike is within 100 feet of the large Respini Creek dike (51), from which it is probably an offshoot.

The Respini Creek dike (51, figure 10, and figure 2, plate 28), the largest of the Santa Cruz intrusions, has an exposed width of 600 feet along the sea-cliff immediately southeast of the mouth of Respini creek, and extends one-fourth of a mile inland. It is composed of rather fine grained, yellowish brown and gray sand, free from bitumen. The sandstone varies from soft friable material, from which the cementing material, if ever present, has been leached, to hard compact stone. The surface of the intrusion is much pitted by the action of the waves and by the weather and is broken by many joint planes. At places it presents a peculiar wavy banded structure, some of the bands being harder than others. The hardness of some of the thin layers that resist the action of the weather is apparently due to iron oxide as a cementing material. At other places there are groups of vertical columns of hard, gray, jointed sandstone, extending to the top of the cliff. Adjacent to these columns, of which there are many groups, the sandstone of the dike is

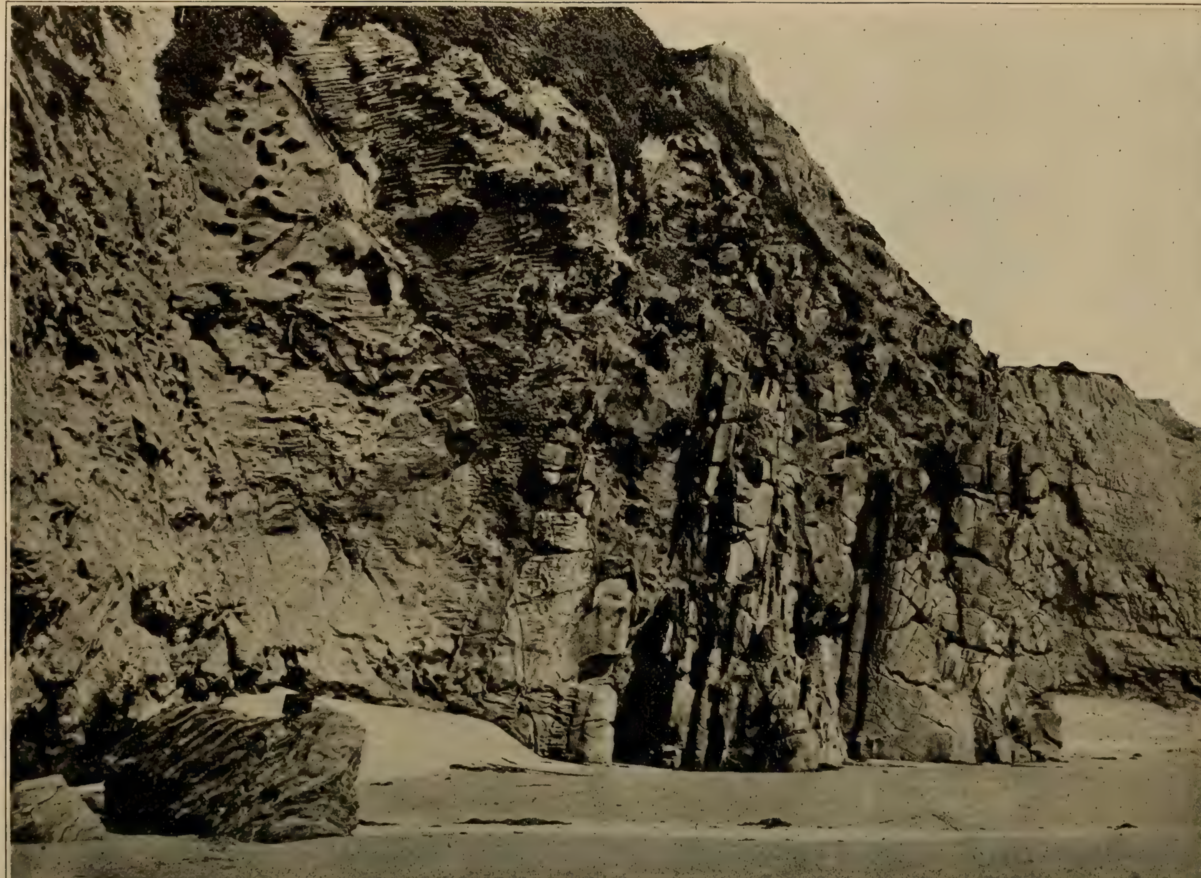
FIGURE 1.—BITUMINOUS SANDSTONE DIKE

Southeast of mouth of Laguna creek, west of Santa Cruz

FIGURE 2.—LARGE SANDSTONE DIKE

South of mouth of Respini creek. View taken looking north

SANDSTONE DIKES



DETAILS OF THE RESPINI CREEK INTRUSION

Vertical columns, thin wavy bands, and pitted and jointed character of rock are well shown

soft, and has the peculiar wavy banded structure mentioned above. Plate 29, and figure 1, plate 30, show the peculiar wavy and columnar structure at the southwest end of the Respini Creek dike.

The wavy layers exposed in this dike strongly suggest flowage of the sand in a liquid medium, and the columns are apparently the filled necks of channels through the sand mass through which liquids and sands were forced up from below and around which those sands were deposited, thus finally building up the entire mass of the dike.

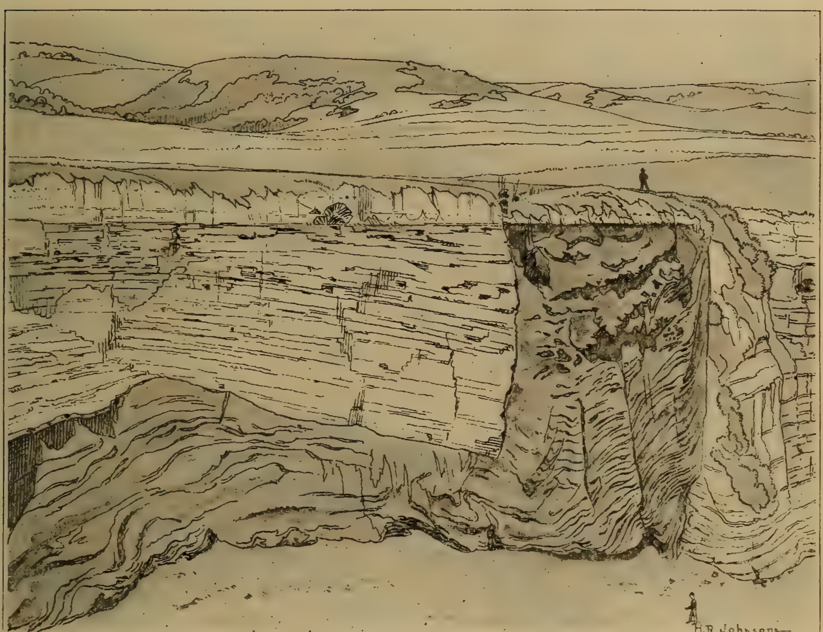


FIGURE 16.—*Sandstone Intrusion at 49, Figure 10.*

Looking east. The wavy banded structure is shown in the vertical part of the intrusion at the right of the picture, and also in the main mass of the intrusion at the left. Sea terraces are shown in the background. At the top of the sea-cliff in the foreground the Pleistocene gravels and sand rest unconformably upon the underlying diatomaceous shales.

Near the top of the sea-cliff and resting on the sandstone is a large lenticular mass of diatom shale, similar to the shales at either side of the intrusion. This fragment is indistinctly seen near the center of figure 2, plate 28. Whether this shale is in place or was lifted up to its present position by the intrusion of the sand is not apparent. The outcrop of the Respini Creek dike, which has an approximate strike of north 45 degrees east, can be traced for one-fourth of a mile from the coast. At the southern side of the intrusion on the coast line the dip of the diatom shales is

12 degrees south ; at the north side the dip is 12 degrees south, 40 degrees west.

Figure 2, plate 28, is from a photograph looking northward, and taken from the point *X*, figure 10. It shows the southwest end of the dike. Plate 29, and figure 1, plate 30, are from photographs and show details of the southwest end of the intrusion, taken near *Y*, figure 10.

It seems to the writer that the only possible explanation of the structural features found in the large Respini Creek dike is that of intrusion of the sand from below along with water or petroleum.

The vertical columns apparently represent the channels through which ascending currents of petroleum * or water or both brought the sands from below, and from which those sands were poured out at the sides, forming the apparent flowage lines. It is believed that the whole mass was built up in this way, and that the bands exposed on the face of the cliff at the present time are merely the exposed edges of the layers which were deposited in the water around the ascending current. It is evident that the mingling of the material from many ascending currents would produce a complicated structure, and only under the most favorable circumstances would a simple deposit be built up of successive layers in its outer portion, and with a structureless mass or plug of sand at its axis. It is evident also that the sand remaining in the channels when these finally became choked would not be composed of bands, but (if it were not entirely structureless) would probably be columnar.†

At 52, just north of the mouth of Respini creek, is a large V-shaped sandstone intrusion, with a width of 190 feet at the top of the sea-cliff, which is 45 feet high, and a width of 30 feet at the bottom. It is composed of light brown and gray sandstone in alternating layers or bands varying in thickness from 1 to 2 or 3 inches. The entire surface is given

* In this connection the notes of Mr Henry M. Cadell on the mud volcanoes of the Irrawaddy valley, in India (the Scottish Geographic Magazine, vol. xlvii, pp. 263–265), are of interest and suggestive of one way, at least, in which clastic intrusions may be formed. These volcanoes are not produced by steam, but, according to Mr Cadell, "are due to the escape of carburetted hydrogen from the oil-bearing strata on the top of the anticline, which rises through the clay beds, mixed with a little water and oil, and slowly bubbles up at certain spots. As the gas and water rises, it brings up a little gray mud, which, on exposure to the air, dries and hardens, while the water evaporates, producing first a low crater basin with a dry rim of mud, then a cone with a crater on the top, in the center of which the gas finds vent."

† In order to note the phenomena of sand depositing from an ascending current of water, a box with a glass side and with a three-fourths inch opening in the bottom, through which water could be supplied under varying pressures, was made by the writer. Sand was then supplied to the ascending current. As sand was supplied a deposit was built up until the box was filled with a mass of sand with a crater at its top, and at its center a vertical neck which finally became choked with sand as the current was shut off. The layers of sand in the mass which had been built up as a crater deposit sloped toward the center. The diameter of the top of the crater varied with the strength of the current, being greater when the current was strong, and less when the current was weak. Miniature conditions very similar to those observed in portions of the large Respini Creek dike and the dike at 52 (next to be described) were produced.

FIGURE 1.—DETAILS OF THE RESPINI CREEK INTRUSION

Vertical columns combined with the wavy thin layers and also pitted and jointed character of rock are well shown

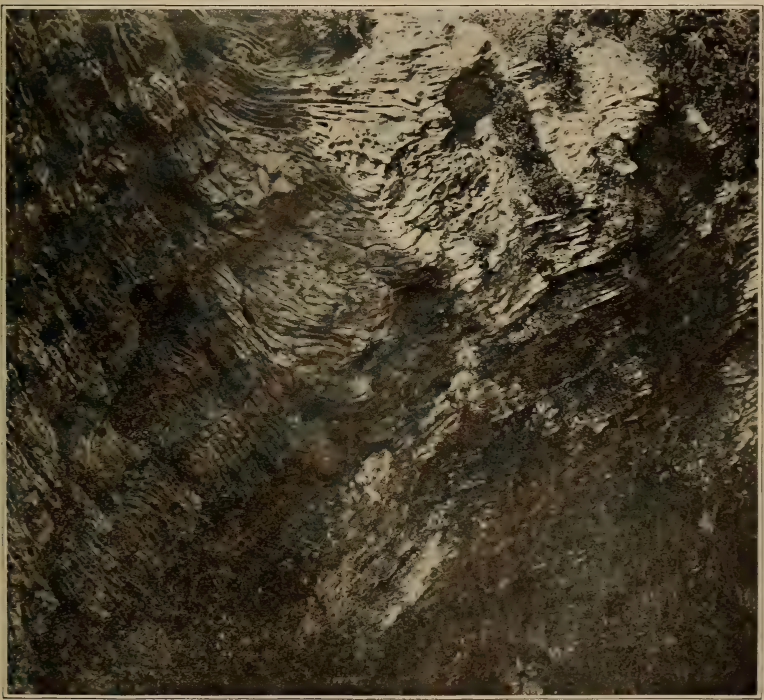


FIGURE 2.—DETAILS OF BANDED STRUCTURE OF MIDDLE PORTION OF DIKE 52

DETAILS OF RESPINI CREEK DIKE AND DIKE 52

a rough and pitted appearance by the leaching away of one or the other sets of these layers, at some places the brown proving the softer, while at others the gray layers are the softer. Some of the sand layers have a very faint bituminous odor, but the intrusion for the most part is free from that substance.

Near the base of the intrusion and at its east side is a large included fragment of diatom shale. The sand layers slope toward the center of the exposure, forming a trough, with a smaller trough at the west side, as shown in figure 17. Figure 2, plate 30, is from a photograph of the central portion of the exposure, and shows the layered structure of the dike. The diatomaceous shale at the east side of the dike dips 15 degrees

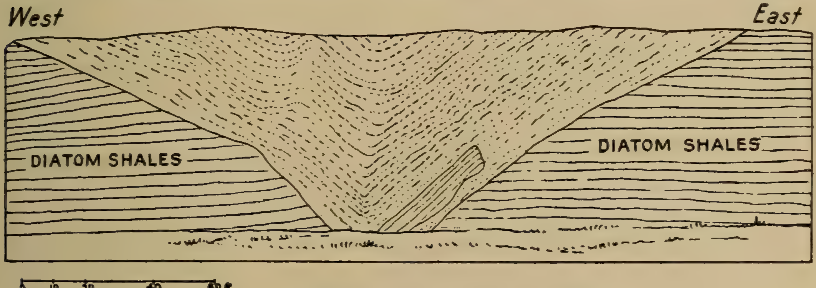


FIGURE 17.—*Diagram Showing Structure of Dike 52.*

This dike is just north of the mouth of Respini creek.

south, 50 degrees west, while that at the west side dips 15 degrees south, 30 degrees west.

The structure exposed in the cross-section of dike 52 (figure 17, and plate 30, figure 2) is such as would be exposed by a vertical plane cutting a mass of sand which had been deposited by a current of water or petroleum coming up from below * and depositing its burden of sand in layers at the angle of repose if the plane were to cut the mass at one side of the vertical channel through which the sand and liquid medium came.

It is believed that this is the explanation of the remarkable sand mass at 52. It should be noted that 52 is but a hundred yards from the large intrusion at 51, with which it is probably connected, the connection being concealed by the sand which covers the space between the two dikes at the mouth of Respini creek.

Dike number 57 is about 200 yards southeast of the mouth of Scott creek, 13 miles west of Santa Cruz. It is the westernmost dike that has

* In this connection the remarks of M. Van den Broeck concerning "le Boulant" are of interest. Bulletin de la Société Belge de Géologie, etc., Bruxelles, tome xv, 1901, pp. 149, 150. See also: Quelques experiences sur l'imbibition du sable par les liquids et le gas, par W. Spring. Ibid., tome xvii, pp. 13-33.

been observed along the coast in this region. This intrusion was observed by Dr Ralph Arnold, and the following notes and diagram (figure 18) are supplied by him.

The sea-cliff is 100 feet high where cut by the dike. The upper 40 feet of the cliff is made up of Pleistocene sands, gravels, and clays, resting unconformably on the diatomaceous Miocene shales. The intrusion has an even thickness of 1 foot from the bottom to the top of the diatomaceous shales. The sides of the fissure inclosing the dike are perfectly straight and clean cut. There is no displacement in the shales on the opposite sides of the intrusion.

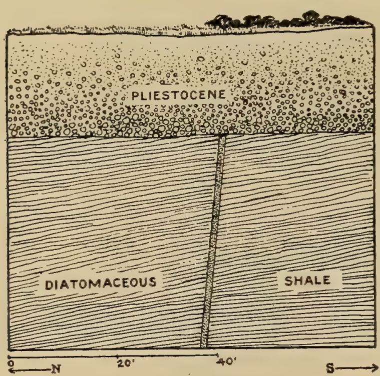


FIGURE 18.—*Diagram of Dike 57.*

Exposed near the mouth of Scott creek, 13 miles northwest of Santa Cruz. This is the westernmost dike observed in the sea-cliff northwest of Santa Cruz.

The dike is composed of rather fine, reddish, compact sand showing a transverse, slightly wavy, banded structure. The material of the dike is totally unlike that of the overlying Pleistocene beds and could not have been derived from them.

Two small dikes, 53, 54, are exposed at the east side of the public road 75 yards south of Coast post-office, and two others, 55, 56, are exposed at the roadside just east of the crossing at Majors creek.

The number of intrusions exposed along the coastline west of Santa Cruz and at the asphalt rock quarries northwest of there indicate that the diatomaceous shales of that region are cut by great numbers of dikes whose outcrops are obscured by the soil.

SUMMARY AND CONCLUSIONS

1. The dikes of the Santa Cruz region cut the diatom shales at angles varying from 0 to 90 degrees. The shales are much jointed in this region.

2. In composition the dikes vary from fine highly bituminized sands to soft sandstones with no bituminous odor. They often contain inclusions of diatom shale.

3. In size they vary from a mass 600 feet across to mere films along joint planes. The small films are usually more or less highly bituminized, while the larger intrusions are usually comparatively free from bitumen.

4. There is usually an irregularly banded and sometimes a columnar structure in the larger intrusions which are practically free from

bitumen. Such structure is absent from the dikes of highly bituminized sands.

5. There are sandstones underlying the shales in which the intrusions occur, of a character similar to the sand of the intrusions. Except for thin beds of sand which overlie some of the smaller intrusions, the nearest overlying sandstones are of probable Pliocene age and many miles distant.

6. The intrusions are at the west side of a faulted monoclinal fold.

7. The sandstones underlying the diatomaceous shales are very soft at some places; at others they are quite hard.

8. It is noticeable that the larger dikes along the coast west of Santa Cruz are comparatively free from bituminous matter, while most of the smaller intrusions, and especially those which do not extend to the top of the sea-cliff, are highly charged with that substance.

9. The absence of overlying sandstones, which could supply the materials for the intrusion, the presence of underlying sandstones, which are bituminous where they outcrop, and the obvious derivation of the dikes at the bituminous rock quarries from these underlying beds leads to the conclusion that most of the dikes of this region were intruded from below, with one or two exceptions.

10. The underlying sandstones were probably formerly oil-bearing, as indicated by their bituminous outcrops at the asphalt rock quarries and elsewhere in the district. They are at present practically barren of oil wherever they have been penetrated by borings. The bituminized sands of the smaller dikes along the coast lead to the conclusion that the former oil-bearing sands were forced into joints in the shales and that the residues from the oil entrapped with the sands in these crevices are still found in the dikes. The absence of bituminous matter in the larger dikes along the coast and the presence of a peculiar flow structure in these leads to the conclusion that the cracks into which they were forced opened to the surface, and that the oil sands were forced into these openings from below by hydrostatic pressure, or the pressure of the overlying beds, or both. These crevices, with their filling of loose sand, probably formed the avenues of escape for the petroleum (providing it was originally present in the underlying beds), and afterwards for the water of the underlying sands. The escaping water must have carried the oil and oil residues from the intrusions.

12. The sands of the dikes may have been intruded rapidly or slowly, and their intrusion may or may not have assisted in the opening of the cracks which received them.

The cracks were probably formed primarily by the elevation of the coast line, which has been going on more or less regularly in this region

probably since the end of Miocene times. At what period the principal dikes were formed is not known.

The intrusions at the asphalt quarries show that bituminized sand, which is plastic, may be forced into small cracks for considerable distances. Large quantities of petroleum or water may, or may not, have been present in the sands along the coast when these were injected into the diatomaceous shales in which they are now found.

The peculiar banded or flow structure in the dikes at 51 and 52 indicates that in these cases, at least, large quantities of the liquid medium came up with the sand. It is not believed that plastic bituminized sands would take on that structure.

In closing the discussion of the Santa Cruz dikes, attention is directed to the fact that the larger of these intrusions afford evidence of the manner in which the water or oil formerly held by the underlying sand beds has escaped from those beds. The importance that may attach to such intrusions, which doubtless occur in other districts underlain by oil sands, is therefore apparent. Should sand intrusions occur near the crests of anticlinal folds, in which the hydrostatic pressure is not sufficient to force the oil all out from below, the sands of the intrusions might then be oil bearing and also lead downward to the underlying oil sands, thus forming an important source of oil supply. When, however, the intrusions are large, when they have low outlets to the surface and occur near the lower edge of the oil reservoir in a region of low hydrostatic pressure (or gas pressure from above), or when they occur at the upper edge of the oil reservoir in a region of high hydrostatic pressure, they are in a position to have completely drained the underlying beds of their oil.

Clastic Dikes observed Elsewhere by the Writer

NEAR STANFORD UNIVERSITY, CALIFORNIA

A number of very small dikes of coarse sands occur in much jointed basalt at the quarries just west of Stanford University.

At the quarry on the east side of San Francisquito creek, the joint blocks near the top of the quarry are angular and irregular. Farther down, the irregular jointing gradually gives way to poorly defined and then to well defined basalt columns.

Overlying the basalt and resting on an old erosion surface is a coarse gray sandstone. Many small dikes occur in this quarry along joint fissures immediately below the overlying sandstone, and also in the basalt mass, as much as 25 feet below the sandstone. In some cases films of sand occur between the basalt columns. Most of the dikes are very

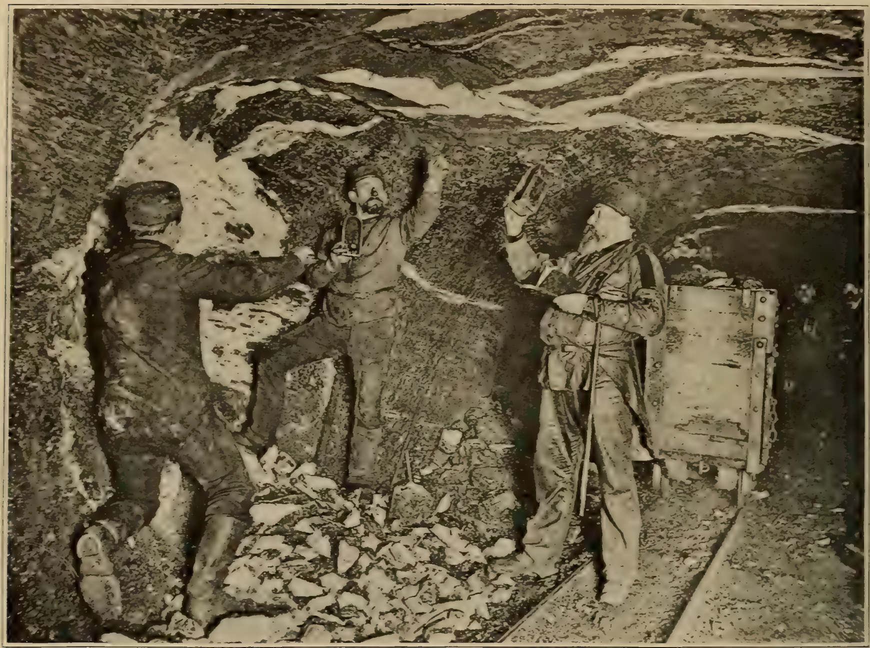


Figure 1.—Sandstone Intrusions in Coal Beds

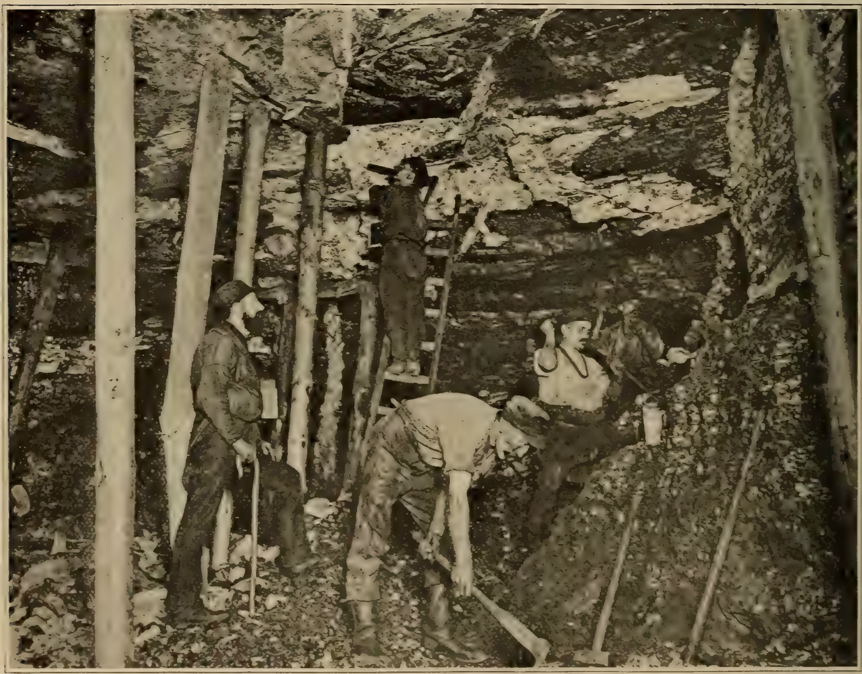


Figure 2.—Sandstone Intrusions in Coal Beds

SANDSTONE DIKES IN COAL BEDS

Oppel shaft, Zaukeroda, near Dresden, Germany. From photographs by A. Börner

thin, ranging in thickness from mere films ⅛ to ¼ inch thick, some of them as much as 2 or 3 inches thick. The relations of two of these small dikes are shown in figure 19. The dikes shown in the figure illustrate the occurrence in this district.

The sandstone of the dikes is similar to that of the overlying beds. The origin of these small dikes is apparent. The joint cracks were formed in the basalt, probably as that material cooled, and these cracks were afterward filled by sand from above, probably with the aid of water, and at the same time that the overlying sands were being deposited.

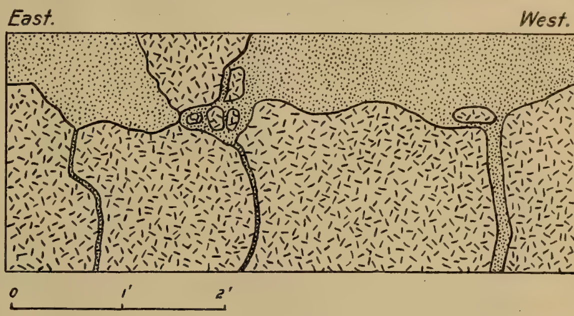


FIGURE 19.—*Diagram of Sandstone Dikes near Stanford University, California.*

These dikes fill fissures along joint planes in basalt. The sand of the dikes came in from above.

NEAR MORRILTON, ARKANSAS

A dike of fine grained sandstone intersects Carboniferous shales on the east bank of the Arkansas river, just below the ferry, 2 miles south of Morrilton, Arkansas. In 1891, when observed by the writer, this dike was exposed for a horizontal distance of about 30 feet. It is but a few inches thick, stands at a high angle, and its contacts with the shales are smooth and sharply defined.

The region is one of interbedded sandstones and shales, and there is nothing to indicate whether the sand in the fissure came from above or below.

AT ZAUKERODA, SAXONY

At the Oppel shaft of the Royal coal mines, at Zaukeroda, near Dresden, Saxony, there are great numbers of dikes of shale and sandstone intersecting the coal beds, and in some cases the overlying shales, in all directions. The dikes vary in thickness from a fraction of an inch to 60 or 75 feet (reported), and in some places they are so numerous as to make up a considerable portion of the mass of the coal beds. The coal bed, which has shale above and shale and sandstone below, is from 12 to 20 feet thick, and this entire thickness is often cut across by dikes which branch, thin out, and intersect each other, and often form a perfect network, seriously interfering with the economical extraction of the

coal. The larger dikes are left by the miners, and in a plan of the mine they show a rectangular arrangement, as though the intrusions had been along the joints of enormous rectangular blocks of the coal. The dikes of these coal beds are undoubtedly intrusions. Figures 1 and 2, plate 31, show the nature of some of these intrusions.

Clastic Dikes previously Described

The following references to literature on clastic dikes are arranged in chronological order. In some cases extracts from the papers are given; in others a few words of explanation and the conclusions are given. A few references to dikes of clay, shale, and sandstone in coal beds are given. Such dikes are common in many coal regions and references to some of those that have been described are inserted in order to bring them to the attention in connection with the subject of clastic dikes. It is also desired to call attention to the similarity between such dikes in coal beds and the clastic intrusions that occur in regions far removed from coal beds.

A number of references are also given to papers by English and other authors concerning pipe-like deposits of sand, of gravel, and of clay, which are found in the chalk and limestones in a number of regions.

Inasmuch as asphaltum is more or less closely associated with many sandstone intrusions and is derived from sedimentary rocks, a number of references are given on the subject of asphalt veins:

Strangways, 1821. The earliest reference to dikes of clastic materials seems to be that of Mr Strangways, who described a number of dikes of clay near the village of Great Pulcovca, in the neighborhood of Saint Petersburg, Russia.*

The dikes intersect limestones and blue clay, and are described at one place as "about two feet wide, and are filled with diluvian gravel of the same nature as that which covers the plain and cliff above."

Cuvier and Brongniart, 1822. In 1822 Brongniart and Cuvier called attention to sand pipes in the neighborhood of Paris.†

Murchison, 1827. In speaking of the rocks of Kintradwell in Somersetshire, in 1827, Murchison says: ‡

> "These grits are traversed by a vein two and a half feet wide, in texture resembling quartz-rock and having a conchoidal fracture; the tilting of the strata in opposite directions at this point indicates some powerful disturbing cause."

That Murchison referred to a dike of hard sandstone instead of to a

* Trans. Geol. Soc. of London, vol. v, 1821, pp. 386, 407, 408, pls. 25, 26, 27, 28.

† Description géognostiques des Environs de Paris, edit. 1822, pp. 76, 134, 141.

‡ Trans. Geol. Soc. of London, 2d series, vol. ii, p. 304.

quartz vein is to be inferred from the remarks upon the subject made by H. Strickland in 1838, in volume v, second series, page 600, of the Transactions of the Geological Society.

Darwin, 1833–1834. While on the voyage of the *Beagle*, in 1833–1834, Darwin observed three dikes in the harbor above Point Desire, at the eastern side of Patagonia.*

One of these dikes is " about four feet wide," and " consists of whitish, indurated tuffaceous matter, precisely like some of the beds intersected by it."

Darwin is of the opinion that at least two of the dikes were formed by the suction of the waves acting in fissures that opened to the surface, and that the material was thus drawn in from above.

On page 117 of the same volume, Darwin notes the occurrence of dikes of tuff cutting volcanic tuff, in the Galapagos archipelago.

Strickland, 1838. In 1838 H. E. Strickland described some dikes of calcareous grit at Ethie, in Rossshire.† The dikes described cut Triassic shales and are composed of very hard sandstone containing some lime carbonate.

The largest dike is 3 feet thick and at least 200 yards long. Two of the dikes are parallel with the shale beds in which they occur, while the others cut more or less directly across the bedding. From two of them branches a few inches thick are given off.

Dana, 1838–1842. While on the exploring expedition under the command of Charles Wilkes, from 1838 to 1842, Professor J. D. Dana observed a number of sandstone dikes on the Columbia river near Astoria, Oregon, and gives figures of three of them.‡

One of them is 5 feet wide, is composed of granitic sandstone, and cuts to the top of the bluff of shales in which it occurs.

Regarding the origin of the dikes near Astoria, Professor Dana says:

> "These pseudo-dikes of sandstone were probably formed after or during the deposition of the sandstone, while the region was yet under water. Fissures were opened, perhaps by the same cause that ejected the basalt of the intersecting dikes, and the fissures were filled at once by the granitic sands, along with an occasional fragment of shale from the walls of the fissure. Their number and irregularity evince that these regions have been often shaken by subterranean forces."

Buckland, 1839. In 1839 Mr Buckland described sand-pipes in the chalk in the region about London, and reached the conclusion that they

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* Geological observations on the volcanic islands and parts of South America visited during the voyage of H. M. S. "Beagle." Second edition, 1876, p. 438.

† Trans. Geol. Soc. of London, 2d series, vol. v, p. 599.

‡ United States exploring expedition, during the years 1838, 1839, 1840, 1841, 1842, under the command of Charles Wilkes, U. S. N. Geology, vol. x, pp. 654–656.

were formed by percolating water forming cavities and letting the superincumbent sands down into the cavities.*

Lyell, 1839. In 1839 Sir Charles Lyell described a number of sand-pipes in the chalk of Norwich, and concluded "that the excavation and filling up of the pipes were gradual and contemporaneous processes."†

Trimmer, 1840–1855. In 1840–1855 Mr Joshua Trimmer ‡ described many sand and gravel pipes occurring in Kent and Norfolk. The cavities containing the sand and gravel pipes are regarded by Mr Trimmer as having been formed as deep, narrow potholes by the wearing action of the waves. Prestwich and other English writers on the subject do not concur in these views of Mr Trimmer.

Leblanc, 1842. M. Leblanc, in 1842, believed the pipes of the Paris basin to be filled conduits through which underground waters formerly came up, carrying with it the materials found in the pipes.§

Melville, 1843. In 1843 Mr Melville called attention to pipes in the Tertiary of the Paris basin and gave sections to illustrate his view of the manner in which waters passing down into the strata around the Paris basin could have been forced up through the strata into the sea, carrying up any soluble or insoluble materials they may have collected.||

Weissenbach, 1850. In 1850 Weissenbach mentioned clastic dikes or "veins" which occur near Naulitz.¶

Prestwich, 1854. In 1854 Joseph Prestwich described a large number of sand and gravel pipes in the Tertiary of the London district, and held the view that these pipes had been formed by the superincumbent sands and gravels being let down into cavities formed in the underlying beds by percolating waters.**

His conclusion regarding these phenomena is stated as follows:

> "I view these sand and gravel pipes in the chalk and other soft calcareous strata as extinct natural water-conduits, which the waters, at different periods, through incessant filtration from a higher water-bearing stratum in their tendency to reach a lower level, gradually and quietly wore for themselves by their solvent action alone; the size of the pipes mainly depending both upon the length of time the operation continued, and also upon the extent of difference of level between the two water-surfaces."

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* Trans. of the Brit. Assoc. for 1839, p. 76.

† London and Edinburgh Phil. Mag., 3d series, vol. xv, Oct., 1839, p. 257.

‡ Proc. of the Geol. Soc., 1840, vol. iii, p. 185; 1842, vol. iv, p. 6; Jour. of the Geol Soc. of London, 1844, vol. i, pp. 300–317; 1852, vol. viii, p. 275; 1854, vol. x, pp. 231–240; 1855, vol. xi, pp. 62–64.

§ Bulletin de la Société Geologique de France, 1er série, xiii, 360–366, Paris, 1842.

|| Bulletin de la Société Geologique de France, 1er série, xiv, Paris, 1843. De la theorie des puits naturels, pp. 182–194.

¶ Gangstudien oder Beiträge zur Kentniss der Erzgange; Herausgegeben von Bernard Cotta; Erster Band; Freiberg, 1850. Oeber Gangformation, von C. G. A. v. Weissenbach, pp. 16, 17.

** Quart. Jour. of the Geol. Soc. of London, vol. ii, 1855. On the origin of the sand and gravel pipes in the chalk of the London Tertiary district, by Joseph Prestwich, pp. 64–84.

Ibid., vol. x, pp. 222–224 and 241.

Prestwich also thinks that many of the pipes in the harder limestones have been formed along the lines of preexisting fissures.

Kirkby, 1860. In 1860 J. W. Kirkby described a number of sand-pipes in the magnesian limestones of Durham.*

These pipes, or narrow sand and clay filled tubes, extend from a thin sandstone down into an underlying limestone. The longest one mentioned has a length of 6 feet. Kirkby concludes that the cavities were formed by solution, by waters passing down from the overlying stratum of sand. The sand is overlain by shales which prevent the water, which finds access to the sand, from escaping in any direction except downward. The sand filling the pipes has been derived from the overlying sand bed, and the filling took place synchronously with the formation of the pipe-like cavities.

A. B. W. and Du Noyer, 1860. In the April Geologist, 1860, A. B. W. calls attention to some irregular vertical veins or thin dikes of dark gray compact limestone, crossing a nearly horizontal bed of red shale in or near the local base of the Old Red sandstone near Templemore.†

In the July Geologist, 1860,‡ Du Noyer suggests as an explanation of the dikes mentioned by A. B. W., that before solidification the shales were elevated above the sea, and sun cracks were formed in them. Afterward the shales were submerged, limestone was deposited, and the cracks of the shale were thus filled. Then, according to Du Noyer, there was a reelevation and removal by erosion of all the limestone except that in the cracks in the shale; then there was another submergence, during which the Old Red sandstone was deposited above the shale in the position it occupies at present.

Foster and Topley, 1865. In 1865 Messrs C. Le Neve Foster and William Topley described a number of pipes of gravel and brick-earth in the Kentish Rag of the Weald.§ They are of the opinion that these pipes are caused by the overlying gravel and clays being let down into cavities formed by the solution and removal of the underlying limestone by acidulated waters.

Whitney, 1865. On page 40, volume i, of the Geological Survey of California (published in 1865), J. D. Whitney notes the occurrence of dike-like masses of sandstones intersecting shales 7 miles southeast of Corral Hollow, in the mount Hamilton range. In regard to the origin of these dikes Whitney says they "seem to have originated in the filling

*The Geologist, London, 1860. On the occurrence of "sand-pipes" in the magnesian limestones of Durham, by J. W. Kirkby, pp. 293–298, 329–336.

† The Geologist, London, 1860, p. 135.

‡ Ibid., pp. 272–273.

§ C. Le Neve Foster and William Topley: On the superficial deposits of the valley of the Medway, with remarks on the denudation of the weald. Quart. Jour. of the Geol. Soc. of London, vol. 21, 1865, pp. 443-459.

of fissures by sand, which has since become indurated." On page 321 he notes similar dikes along Bee creek and Alderson gulch, in Shasta county.

Moore, 1867. In 1867 Mr Charles Moore described a number of remarkable clastic dikes of Liassic age which cut Carboniferous limestones in the region of the Mendip hills, Somersetshire, England.*

The most interesting group of dikes described by Mr Moore is thta exposed in a limestone quarry near the village of Holwell. A cross-section of this quarry is given and the dikes shown in it are described.

The dikes illustrated are of limestone principally and are very fossiliferous in some cases. According to Mr Moore, the limestone of the dikes differs considerably in character from that of the intervening Carboniferous stone. One of these dikes is described † as being

"very various in color (cream-colored, yellow, pink, green, or blue), showing by its occasional thinly laminated structure that it was in fact very slowly deposited. This incloses angular fragments of Carboniferous limestone. In this vein may be found occasional nests of Rhaetic remains mixed with *Rhynchonella variabilis, Terebratula punctata*, and *Delphinula nuda*, Moore, and a crustacean claw of Liassic age. At the base of the quarry it attains a thickness of 13 feet."

Mr Moore calls attention to the fact that a number of similar dikes other than those described occur in the Holwell locality. That the Liassic dikes are not confined here to one small locality is shown by the fact that 9 miles west of the Holwell locality a dike occurs in a large quarry.

Eight miles still farther west, at the Charter House Liassic lead mine, 2½ miles distant from the nearest known horizontal deposit of Liassic age, Mr Moore found in an old shaft, at a depth of 270 feet, "a deposit of deep blue or greenish clay, 12 feet thick, giving the appearance of having been deposited in thin horizontal layers, therefore slowly, whilst at other spots it presented a more conglomerate character, and contained driftwood pebbles, etc.," and from which were collected about 95 species of very delicately preserved lower Liassic fossils.

As indicating the mode of formation of this deposit, Mr Moore says:

"There can be little doubt that the Liassic seas at this period occupied the profound depths of the Carboniferous limestone fissures, within which the organic remains were probably living, contemporaneously with the deposition of Liassic beds at other points. The delicacy and perfect condition of the fossils show that their presence is not due to the denudation and the redisposition of previously existing beds within the fissures."

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* Charles Moore: On abnormal conditions of secondary deposits when connected with the Somersetshire and South Wales coal basin, and on the age of the Sutton and Southerdown series. Quart. Jour. of the Geol. Soc. of London, vol. xxiii, 1867, pp. 481 et seq.

† Loc. cit., p. 485.

Other dikes in the region of the Mendips hills are described in more or less detail by Mr Moore. Regarding the origin of these remarkable dikes Mr Moore has the following to say: *

"Under certain circumstances they (the *Liassic limestones*) are found either resting immediately upon the limestone (*Carboniferous*),† filling up any basins or irregularities in its surface (when there have been any opportunities), passing down into its fissures, or lying against the southern outer edge of what there is every reason to suppose was the ancient Rhaetic and Liassic coastline presented by the Mendips at these and subsequent periods."

Further, in remarking on the origin of the dikes near Holwell, the following is said: ‡

"The curious phenomena here observed, and especially the thickening of the dikes of more recent age downwards, are somewhat difficult to account for. An analogous state of things might arise, could we suppose that the Carboniferous limestone at this point formed the wave-washed cliff of the Liassic sea, and that its caverns were subsequently filled by Liassic deposits. A longitudinal section at their junction would then show similar conditions; but we cannot strictly adopt this idea, from the fact that the same phenomena prevail throughout the whole line of the Carboniferous limestone, and that the veins are continued to unascertained depths."

Regarding the age of the dikes described by Mr Moore, Professor Woodward says: §

"It is possible that there were open fissures on the sea-coast in Liassic times, as we see at the present day in the Carboniferous limestone near Sutton in South Wales, but the admixture of fossils suggests that in-fillings may have taken place at various periods, in some cases perhaps subsequent to the Jurassic epoch. In some of their features these Liassic veins resemble chasms and 'pipes' in the Kentish Rag of Maidstone, where in-fillings of fossiliferous brick earth occur."

Oldham and Mallet, 1872. In 1872 Messrs Oldham and Mallet mentioned the formation of fissures, and the injection of sand into them, in Cachar, India, by the earthquake of 1869. ||

During the earthquake many fissures were formed over a wide area in "layers of stiff clay and mere sandy deposits some 25 or 30 feet thick, which, throughout, rest upon a bed of some 3, 5, or 6 feet thick of bluish silt or sandy ooze . . ."

The underlying watery "silt or sandy ooze" was forced up into the fissures under such pressure in some cases as to cause it to spout up above

* Ibid., p. 482.

† Italics in parentheses are the present writer's.

‡ Ibid., p. 482.

§ Horace B. Woodward: The Jurassic Rocks of Great Britain. The Lias of England and Wales. (Yorkshire excepted.) Memoirs of the Geological Survey of the United Kingdom, vol. iii, p. 98.

|| Notice of some of the secondary effects of the earthquake of 10th January, 1869, in Cachar. Communicated by Doctor Oldham. With remarks by Robert Mallet. Quart. Jour. of the Geol. Soc. of London, vol. 28, 1872, pp. 255–270.

the surface, and in others to cause only slight overflow. As the water sank back into the fissures an inverted cone structure was formed in some cases.

Fontaine, 1873. In 1873 Professor Wm. M. Fontaine described the Grahamite deposit in Ritchie county, West Virginia.*

Wurtz, 1869. In 1869 Mr Henry Wurtz described † the Ritchie county Grahamite vein, which intersects Carboniferous sandstones and shales in West Virginia. He reaches the conclusion that the material in it came from underlying strata intersected by the fissure in which the deposit occurs.

A dike of Grahamite in Colorado is also mentioned by Mr Wurtz.

Milne, 1874. In 1874 John Milne described a schistose dike which intersects black slates on Facheux bay, Newfoundlaud.‡

The dike described is 3 feet 6 inches wide at the top and 2 feet 3 inches wide at the bottom; it contains carbonaceous matter. Other similar dikes are mentioned as occurring in the district.

Stevenson, 1875. In 1875 J. J. Stevenson mentioned and described a number of clay dikes occurring in the coal beds of western Pennsylvania.§ Clay dikes or "veins" coming from both above and below are mentioned on page 276. On pape 279 of Report K a case is mentioned where the coal for 2½ feet at each side of a 6-inch intrusion "is thrown up sharply and without any snapping at the angles, but the upturned portion is badly shattered." On page 316 a 7-foot clay intrusion is mentioned.

White, 1875. In 1875 I. C. White mentioned "clay veins" occurring in the bituminous coal region of western Pennsylvania.||

Kimball, 1876. In 1876 J. P. Kimball described a deposit of Grahamite, which has been intruded from below, in Mexico.¶ This deposit intersects shales at a low anticlinal fold, and at the contact of the shales with overlying conglomerates and sandstones spreads out into a lenticular mass.

Richardson, 1877. In his report on the coal fields of Nanimo and Comax ** calls attention to sandstone dikes in shale and remarks:

"One of the so-called dikes is quite vertical, seven feet thick, and strikes north 73 degrees east. From the character of the walls of some of these dikes it is sup-

* Am. Jour. Sci. and Arts, 3d series, vol. vi, pp. 409–416.

† On the Grahamite of West Virginia and the New Colorado Resinoid. Proc. Amer. Assoc. Adv. Sci., vol. xviii, pp. 124–135.

‡ Quart. Jour. of the Geol. Soc. of London, vol. xxx, p. 731.

§ Sec. Geol. Survey of Pennsylvania, 1875, Report K, pp. 53, 228, 276, 279, 306, 307, 308, 316, 324, 326. Also Report K K K, pp. 295–301, and Report K K, pl. 876.

|| Sec. Geol. Survey of Pennsylvania, Report Q, pp. 74, 78.

¶ James P. Kimball: On the occurrence of Grahamite in the Huasteca, Mexico, etc. The Amer. Jour. Sci., 3d series, vol. xii, 1876, pp. 277–286.

** Report of Progress for 1876–1877 of the Geol. Survey of Canada, p. 186.

posed that they are due to ditch-like excavations made in the shale by running water, which have subsequently been filled with sand by the same agency."

Moore, 1880. In 1880 Mr Charles Moore described a number of fossiliferous dikes or "veins" intersecting Carboniferous limestones in the Bristol region,* Great Britain.

Irving, 1883. In his report on the copper-bearing rocks of the Lake Superior region in 1883, R. D. Irving mentions sandstone dikes cutting underlying diabase on the shores of lake Superior. He says:†

"A number of places were noted on the north shore where the overlying sandstone bed has been removed and large surfaces of the underlying diabase, sometimes many hundred feet in length, present the singular appearance of being intersected by veins of sandstone, the seeming veins crossing each other, zigzagging, and branching like true vein-formed material."

Orton, 1884. In 1884 Edward Orton called attention to "clay veins" in coal, and makes suggestions regarding the manner of their formation.‡

Wall, 1884. In 1884 J. Sutton Wall mentioned and described a number of clay "veins" or dikes in the coal beds of the Monongahela River region of Pennsylvania.§

Dutton, 1889. In his paper on the Charleston earthquake of 1886 || Captain Dutton calls attention to large numbers of craterlets from which quantities of water and sand were discharged during the earthquake. The sand came from beds of quicksand which were near the surface.

Humphreys, 1886. In 1886 A. N. Humphreys observed and figured a number of clay and slack "veins" or dikes in coal beds in Pennsylvania. They are described as varying in thickness from 6 inches to 6 feet. According to Mr Humphreys, the fissures were "formed partly by tensile and partly by torsional strain upon the seam," and the fissures thus produced "became filled by clay infiltrations from the shales and fragments of sandstone in the overlying strata."¶

Diller, 1890. The most interesting and important paper on the subject of sandstone dikes is that of Diller,** published in 1890.

Mr Diller describes a large number of dikes which intersect inclined Cretaceous sandstones and shales about the headwaters of Cottonwood

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*Charles Moore: On abnormal geological deposits in the Bristol district. Quart. Jour. of the Geol. Soc. of London, vol. 37, pp. 67–82. See pp. 70, 73–74.

†Roland D. Irving: The copper-bearing rocks of lake Superior. Monograph V of the U. S. Geol. Survey, pp. 139–140. See also pp. 292–293.

‡Geol. Survey of Ohio, vol. v (Economic Geology), p. 143.

§Second Geol. Survey of Pennsylvania. Report K 4, pp. 48, 50, 60, 62, 121, 163, 178, 187.

||Capt. Clarence E. Dutton: The Charleston earthquake of August 31, 1886. Ninth Ann. Rept. U. S. Geol. Survey, pp. 209–528. See pp. 284, 297, 301, 302, etc.

¶Ann. Report of the Geol. Survey of Penna. for 1886, pt. i, pp. 447–451.

**J. S. Diller: Sandstone dikes. Bull. Geol. Soc. Am., vol. 1, 1890, pp. 411–442.

creek, west of Red Bluff, California (the locality is indicated at 1, figure 1 of this paper). One of these intrusions, the Great dike, is of micaceous sandstone, somewhat harder than the adjacent shales, and can be traced more or less continuously for 9½ miles.

The dikes stand about vertical (varying from vertical to 60 degrees) and have a general northeast-southwest trend, which varies from north 20 degrees east to north 71 degrees east.

Regarding the relations between the dikes and joints in the adjacent strata, Diller says:

"The dikes are parellel to the joints in their vicinity, and so related to them as to indicate that the joints have not been produced by the dikes, but that, on the contrary, the position of the dikes has been determined by the joints."

The dikes frequently contain small shale inclusions; they are occasionally banded near the edges, the banding being vertical and "due to streaks of finer and coarser sand."

The dikes often have two sets of fractures, one set being transverse and the other being parallel to the sides. The intrusions weather more slowly than the inclosing rocks in many cases and project from the hillsides as stone walls.

The dikes are composed of gray micaceous sandstone, which weathers brown. Besides mica and quartz sand, the rock contains a number of other minerals, among which is carbonate of lime, which is the cementing material of the rock. The mica scales of the dikes were found to be arranged parallel to the sides of the dikes, a position which they would assume if carried there by ascending currents of water.

After a careful examination of the phenomena presented by the dikes west of Red Bluff, Mr Diller reaches the conclusion that the sand was forced into the fissures from below, and thinks the dikes "record seismic movement during the Tertiary." Concerning the force by which the sand was injected into the fissures, he says:

"It appears that if by any means a fissure were suddenly formed from the surface down to the sand saturated with water the latter would rise in the fissure, and if the hydrostatic pressure were sufficiently great the water would rush forth, carrying the sand with it to fill the fissure, and, like an artesian well, overflow upon the surface."

In support of this view, the phenomena of sand and water being ejected from fissures during earthquakes in various regions are cited.

Hilgard, 1890. In 1890 E. W. Hilgard described the deposits of the Ventura Asphalt Company, situated 5 miles in a northwesterly direction from San Buena Ventura, California.*

* E. W. Hilgard: Report on the asphaltum mine of the Ventura Asphalt Company. California State Mining Bureau, Tenth Annual Report of the State Mineralogist, 1890, pp. 763-772.

The deposits described occur as veins or dikes in clays. According to Hilgard, the deposits are composed of bitumen, mixed "with 75 to 80 per cent of a fine siliceous clay, substantially identical with the wall material and main mass of the formation in which it occurs." The dikes vary greatly in thickness and give off branches and at some places contain large pockets, and Hilgard believes them to be intrusions from below, having been forced by pressure into fractures in the overlying clays in which they are now found.

McGee, 1900. On page 440, volume 1, Bulletin of the Geological Society of America, Mr Diller mentions the discovery by W J McGee of a number of small sandstone dikes which intersect Eocene strata at Corinne, Mississippi. It is also noted that some years previous to 1890 Mr C. D. Walcott had collected a fragment of a sandstone dike intersecting limestone at lake Champlain.

Hay, 1891. In 1891 Robert Hay described two sandstone dikes in northwestern Nebraska, 2 miles southward from the town of Cadrow.* The dikes are half a mile apart and are regarded by Hay as having been "intruded before the completion of the deposit of the soft clays and marls" of the White River beds in which they occur. The intrusions stand up in wall-like outcrops, being harder than the inclosing rocks. Regarding their origin Hay says :

"These dikes may be related to the phenomena of mud volcanoes as they were certainly intruded from below."

Keyes, 1893. C. R. Keyes mentions the occurrence of clays and sandstones filling fissures in the Coal Measures of Iowa in 1893. These dikes are usually from a few inches to a foot or more thick. and "more or less vertical, with very irregular borders." One such intrusion is figured.†

Stone, 1893. In 1893 Professor George H. Stone pointed out the fact that the "Pinkeye lode" in the Turkey creek mining district, southwest of Pikes peak, is a dike of sandstone intersecting granite gneiss; the dike trends almost north and south.‡

Abbott, 1894. Mr W. J. Lewis Abbott described fissures filled with fossiliferous fragmental materials, near Ightham, Kent, in 1894.§ Mr Abbott believes that "the deposit was introduced into the fissures by a river."

Cross, 1894. In 1894 Whitman Cross described ‖ a number of sand-

* Robert Hay: Sandstone dikes in northwestern Nebraska. Bull. Geol. Soc. Am., vol. 3, 1892, pp. 50–55.

† Charles Rollin Keyes: Crustal adjustment in the upper Mississippi. Bull. Geol. Soc. Am., vol. 5, 1893, p. 239.

‡ George H. Stone: The Turkey Creek mining district, El Paso county, Colorado. Eng. and Min. Jour., vol. lvi, 1893, p. 262.

§ Quart. Jour. Geol. Soc. of London, vol. 40, 1894, pp. 171–187. A list of vertebrate fossils from hese fissures is given in an accompanying paper by Mr E. T. Newton.

‖ Whitman Cross: Intrusive sandstone dikes in granite. Bull. Geol. Soc. Am., vol. 5, 1893 pp. 225–230.

stone dikes in granites in the Pikes Peak region in Colorado. The dikes are of tough even grained sandstones, and vary in thickness from films in the granites to masses several hundred feet in thickness, some of which can be traced for a mile. In speaking of them Cross says:

"The dikes have a general trend parallel to the belt in which they occur. They stand vertical or have a steep dip to the northeast, and often appear as a complex of nearly parallel fissures with many branches and connecting arms. In width they vary greatly. The larger number are a few inches or a few feet thick, but many of the smaller branches thin out to a mere film. On the other hand, several dikes are many yards wide, and two form prominent ridges with a width of from two to three hundred yards each. * * * The larger dikes form ridges with narrow crests rising abruptly three or four hundred feet above the parallel gulches."

No explanation is given of the origin of the dikes, but Cross suggests that possibly the fissures in which they occur were formed "during some period of orographic movement," inasmuch as the dike system and the structural axis of the Front ranges coincide in direction.

Eldridge, 1896. The uintaite (gilsonite) deposits of eastern Utah, which occur as veins, were described by G. H. Eldridge in 1895–1896.*

Some of the veins are vertical, while others dip at high angles. They have a general northwest strike, and vary in thickness from a fraction of an inch to eighteen feet. They vary "in length from a few hundred yards to eight or ten miles," and in strike from north 35 degrees west to north 55 degrees west. They occur in the Green River limestones, shales, and sandstones. The limestones and shales are largely bituminous. Regarding the origin of the veins Eldridge says:

"The condition in which the gilsonite found its way into the veins seems most probably to have been that of a plastic mass coming from below under pressure."

Pavlow, 1896. In the Geological Magazine for February, 1896, † Dr A. P. Pavlow describes a sandstone dike which cuts horizontally stratified gray and black clays near the village of Yavley, in the district of Alatyr, in Russia.

The sandstone composing the dike contains fossils of Tertiary age, while the clays cut by it are of Lower Cretaceous age. The nearest sand and sandstones of Tertiary age that are mentioned are about 12 miles distant from the dike, and in the southern part of the province of Simbirsh; there the Cretaceous beds are overlain by Tertiary sands and sandstones. The surface of the country in the district of Alatyr and about the dike is covered by alluvial sands unlike the sands of the dike.

* George Holman Eldridge: The uintaite (gilsonite) deposits of Utah. Seventeenth Ann. Rept. U. S. Geol. Survey, part i, Washington, 1896, pp. 909–949.

† A. P. Pavlow: On dikes of Oligocene sandstone in the Neocomian clays of the District of Alatyr, in Russia. The Geological Magazine, new series, decade iv, vol. iii, 1896, pp. 49–53.

According to Doctor Pavlow, this dike is an isolated fragment of Tertiary sediments caught in a crevice formed in the Cretaceous clays when the Tertiary sea covered the region. The Tertiary sea retreated later, and all the other sediments of Tertiary age were removed by erosion prior to the deposition of the alluvial material that now covers the region, leaving the dike as the only evidence that the Tertiary sea once covered the locality in which it occurs.

Ashley, 1897. In the proceedings of the Indiana Academy of Science for 1897, pages 242–250, Dr George H. Ashley describes and figures a number of "clay veins" observed in the coal fields of Indiana. He also refers to many "clay veins" in his report on the coal fields of Indiana in the twenty-third annual report of the Indiana Geological Survey.

Crosby, 1897. In Science for April 16, 1897,* Professor W. O. Crosby gives an abstract of a paper previously read before the Boston Society of Natural History on the Great fault and accompanying sandstone dikes of Ute pass, Colorado, in which he calls attenion to the salient features of the dikes previously described by Cross, and also to the continuation of those dikes to the southeast. Regarding the distribution of the dikes studied by him, Professor Crosby says:

"I have succeeded in tracing the sandstone dikes from the vicinity of the Iron spring, in Manitou, northwest along the Great fault 2 miles, or a little farther than the sedimentary rocks extend, and southeastward from Manitou along the base of the mountains, and closely following the Ute fault, to Cheyenne canyon and beyond, a distance of 6 miles. The dikes of this series vary in width up to 500 or 600 feet. A large dike usually follows the main line of displacement, separating the sedimentary rocks and granite, with one to several other dikes closely parallel with it in the granite."

The dikes have usually a southwesterly hade of from 5 degrees to 75 degrees from the vertical, and often present "slickensided shear planes at corresponding angles."

Regarding the material of these dikes, which vary in thickness from mere films to the great masses noted above, he says:

"Although the rock is prevailingly a fine and even grained gray and reddish brown sandstone, identical with that described by Cross, much of it is decidedly coarser, and at several points it is distinctly conglomerate. In several dikes, also, the sandstone is more or less distinctly stratified."

Crosby is of the opinion that the dikes date from the formation of the Ute fault, with which they are so closely associated; that fault fissures were filled by overlying, unconsolidated sands passing down into the fissures at the time of faulting, and that the extremely thick masses of sand represent areas where "sheets of granite of varying width and bor-

*Science, new series, vol. v, 1897, pp. 604–607.

dered by complementary faults have settled down relatively to the bordering masses" and have carried the overlying sands down with them.

Gresley, 1897. In 1897 W. S. Gresley described and figured a number of clay "veins" or dikes in the Pennsylvania coal beds and elsewhere.*

Whitten, 1897. In the Proceedings of the Indiana Academy of Science for 1897, pp. 234–240, W. W. Whitten describes pockets of sand in clays and dikes of clay in sand in glacial deposits at South Bend, Ind. Some of the dikes extend downward from 4 to 8 feet into underlying sands.

White, 1898. In a paper on the Origin of Grahamite, in 1898 Professor I. C. White mentions the Ritchie county, West Virginia, vein, and concludes that its material came mostly from oil sands which lie 1,530 feet below.† The deposit is two-thirds of a mile long, and varies in thickness from a few inches to 4 or 5 feet.

Grabau, 1900. In 1900 A. W. Grabau described a sandstone dike in the Bullhead limestone in Erie county, New York.‡ The dike is squarely cut off at the top, where the Onondaga limestone rests on its truncated end. Its width is about 2 feet, and it sends off numerous branches into the limestones that inclose it. The branches are very irregular, and sometimes appear as much as 30 feet from the main dike, from which they are apparently isolated. Grabau thinks that the formation of the fissure and "more or less violent injection of the sand" from above occurred simultaneously.

Greenly, 1900. In 1900 Edward Greenly described a number of pipes or plugs of sandstone that penetrate limestones on the east coast of Anglesey, Wales.§

Ransome, 1900. In volume xxx of the Transactions of the American Institute of Mining Engineers,|| F. L. Ransome describes a dike of shale fragments, pebbles, and other material which cuts horizontal sandstones near Ouray, Colorado. Regarding its origin he says:

"A fissure was formed, accompanied by some faulting, and was filled, chiefly from above, by fragments of fissile black shale, which does not occur in the stratigraphically lower beds exposed in the immediate vicinity, and partly by material from the lower light-colored beds, forming the present wall. The fragments from both sources were well mixed together, and probably formed a stiff mud crowded with fragments of shale."

The dike is known to extend to a depth of 730 feet.

* W. S. Gresley: Clay-veins vertically intersecting Coal Measures. Bull. Geol. Soc. Am., vol. 9, pp. 35–58.

† I. C. White: Origin of Grahamite. Bull. Geol. Soc. Am., vol. 10, 1898, pp. 277–284.

‡ Bull. Geol. Soc. Am., vol. 11, 1899–1900, pp. 357–361.

§ Edward Greenly: On sandstone pipes in the Carboniferous limestone at Dwlban point, East Anglesey. The Geological Magazine, new series, decade iv, vol. vii, pp. 20–24.

Edward Greenly: On deflected glacial striæ at Dwlban point, East Anglesey. Ibid., pp. 24–25.

|| F. L. Ransome: A peculiar clastic dike near Ouray, Colorado, and its associated deposit of silver ore. Trans. Amer. Inst. of Min. Engs., vol. xxx, 1900, pp. 227–236.

Eldridge, 1901. In his report on the Asphalt and Bituminous Rock Deposits of the United States in 1901,* Mr Eldridge describes many intrusions of asphalt and bituminized sands in various parts of the United States. Veins or dike-like deposits are cited from the following states:

California.—In the Point Arena district, 110 miles north of San Francisco, joints in shales, filled with bitumen, are mentioned (page 380). In the Santa Cruz district, some of the dikes at the asphalt quarries, described in the preceding pages of the present paper (notably numbers 23, 24, and 26) are mentioned and figured.†

In the Santa Maria district asphalt veins which intersect Miocene shales and overlying Pliocene sandstones are described and figured.‡ They give off branches and are very irregular in thickness. Asphalt veins are noted in the Las Alamos region, in Santa Barbara county.§

A number of asphalt veins are noted and described in the southern coast region (west of the Santa Ynez range) and in the asphalt district, 50 miles west of Bakersfield.||

Utah.—The uintaite, wurtzlite, nigrite, and azocerite veins of Utah are described, and a number of them are figured.¶

Colorado.—An asphalt vein in the Middle park, Colorado, is described.**

Indian Territory.—Veins are mentioned in the Ten Mile district,†† the Page district, ‡‡ and the Buckhorn district, §§ and in the Brunswick district. |||| Veinlets of quartz sand are also mentioned.¶¶

West Virginia.—The Ritchie County Grahamite vein is described, and the origin of the vein is discussed.***

Branner and Newsom, 1901. A paper describing some of the dikes west of Santa Cruz, California, was read before Section E of the American Association for the Advancement of Science, at Denver, August, 1901.

Branner, 1902. A dike of limestone in shale in the bed of Searsville creek, 4 miles southwest of Stanford University, was observed by Doctor Branner in 1892.

Arnold, 1902. In an unpublished paper, in 1902, Dr Ralph Arnold maps and describes a number of hard fine grained limestone dikes cutting igneous tufas on the west slope of the Santa Cruz mountains, 7 miles southwest of Stanford University, California.

General Summary

Following is a summary of some of the facts brought out by various writers in regard to the character and origin of clastic dikes, including

* Twenty-second Ann. Report U. S. Geol. Survey, pt. i, pp. 209–464.
† Pp. 386, 388 et seq., 403, 405, 407, pls. lxvii, lxviii.
‡ Loc. cit., pp. 426–429.
§ Loc. cit., pp. 438, 439.
|| Loc. cit., pp. 441–452.
¶ Loc. cit., pp. 331–364.
** Loc. cit., pp. 327–330.
†† Loc. cit., pp. 267, 268.
‡‡ Loc. cit., p. 270.
§§ Loc. cit., pp. 283, 295, 296.
|||| Loc. cit., p. 310.
¶¶ Loc. cit., p. 305.
*** Loc. cit., pp. 233–238.

asphalt veins and clay, shale, and sand " veins " in coal beds, and clay, sand, and gravel " pipes ":

1. Dikes of asphalt, clay, gravel, bituminized and unbituminized sands, hard sandstones, and limestone have been described.

2. The rocks intersected by these dikes include granite, sandstones, sand, shale, clay, and limestone.

3. If the authors are correct in their deductions, clastic dikes have been formed in the following ways:

(*a*) By injection of material from below along with water, petroleum, or petroleum residues. The injection has been due to hydrostatic pressure, pressure from overlying beds, pressure from gas, or from combinations of these. Injection from below is the commonest method of their formation.

(*b*) By injection from above.

(*c*) By material dropping into open fissures from above with or without the aid of water.

(*d*) By material being let down gradually from above, synchronously with the slow formation (by leaching of water) of openings in underlying calcareous rocks.

(*e*) By deposition of sediments in fissures, partially or entirely under the sea.

4. Coal beds are particularly favorable for the formation of clay and sand intrusions.*

In closing this discussion, attention is directed to the fact that conditions favorable to the formation of clastic dikes by intrusion are produced when any unsolidified sedimentary deposit, be it sand, clay, or calcareous material, is covered by a later deposit of any kind which solidifies before the solidification of the underlying sediments. Under such conditions the entrapped unsolidified sediments may be forced into joints or fissures in the enclosing hardened rocks, should such fissures be formed. Clastic dikes may also be produced by the pressure of overlying strata squeezing soft unresisting rocks, such as shales, into cracks in either overlying or underlying rocks which have a greater crushing strength than the entrapped beds.

When these facts are borne in mind, it no longer seems surprising that clastic dikes should occur in great variety, both as to composing materials and surrounding conditions.

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* It is not surprising that beds of vegetable matter undergoing the changes necessary to convert them into coal should become much fissured, neither is it surprising that clay and sand from the strata lying above and below should be squeezed into those fissures, forming the " veins," "dikes," "spars," etc., of the coal miners. The "swelling" or creeping of shale (due to pressure) in the floors of deep coal mine workings is very suggestive of the manner in which sand, clay, and shale dikes in coal beds have been produced.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 14, PP. 269-276 JULY 15, 1903

SYNTHESIS OF CHALCOCITE AND ITS GENESIS AT BUTTE MONTANA

BY HORACE V. WINCHELL

(*Read before the Cordilleran Section of the Society December 30, 1902*)

CONTENTS

Copper Production of Butte

Since 1880 the mines of Butte, Montana, have produced approximately 1,250,000 tons of fine copper. They are now yielding about 200,000,000 pounds per annum, and have attained a maximum depth of 2,200 feet.

Notwithstanding the statements of some writers on ore deposits,* the copper ore of this mining camp is not chalcopyrite, nor is this mineral at all common here. Indeed, it is about as rare as covellite, and a good specimen of either is difficult to procure.

Principal Ore Mineral

Chalcocite is the principal copper mineral, although bornite and enargite are common; and it is probable that more than 75 per cent of the total output of Butte copper has come from the smelting of the mineral chalcocite or copper glance. It is found in all the mines and on all levels from the highest unoxidized level to the bottom workings. It occurs in small crystalline specks, in black powder, and in massive

* Ed. Fuchs et L. De Launay: Traité des Gîtes Minéraux et Metallifères, vol. ii, pp. 263, 265. Eissler: Hydro-Metallurgy of Copper, p. 29.

veins, sometimes many feet in thickness and of most remarkable vertical and lateral extent.

Paragenesis of Chalcocite in Butte

A study of the veins and ores and the paragenesis of the various minerals furnishes convincing proof that the copper glance is one of the latest minerals to be formed in the veins. It occurs crystallized or massive on pyrite, quartz, zinc blende, altered granite, and enargite. It fills fault crevices and fractures either in the veins or the country rock. It is also found in extremely thin films on pyrite, chalcopyrite, covellite, and blende, as well as upon the non-metallic rock and vein minerals.

The lodes themselves are quartzose veins and represent more or less completely replaced country granite. The nature of this granite has been fully described by Mr W. H. Weed.*

There have been two or more separate periods of fracturing and mineralization in the copper area; but chalcocite is found in the fractures of all ages. It is frequently found cementing vein minerals like pyrite which may have been broken apart by earth movements or internal strains. It is also found in great purity and abundance associated with the clay "gouges" of strike or cross-faults, where there is the best opportunity for the circulation of waters from the surface. As depth increases the percentage of pyrite and enargite increases in comparison with that of chalcocite. While the ores of the camp, as mined, may have averaged 8 per cent or 10 per cent copper for the first thousand feet from the surface, they will not exceed an average of 6 per cent copper for the second thousand feet of vertical extent. It is impossible to arrive at exact figures as to the ratio of chalcocite to total copper; but it is a fact that the percentage of chalcocite is decreasing, and that of enargite increasing, with the depth of the mines.

Chemistry of Copper Sulphide

Coming now to the question of the genesis of this chalcocite, it should be borne in mind that copper glance or chalcocite is cuprous sulphide (Cu_2S), and that covellite is cupric sulphide (CuS).

It should also be remembered that hydrogen sulphide and soluble sulphides normally precipitate CuS (not Cu_2S) from copper solutions, whether acid or alkaline.† Cupric salts, with an excess of hydrogen sulphide, always yield an appreciable amount of cuprous sulphide; ‡

* Journal of Geology, vol. vii, no. 8, pp. 737–750.

† Douglas and Prescott's Qualitative Analysis, 7th edition, p. 89.

‡ Brauner: C. N., 1896, 74, 99; Compt. rend., 1884, 98, 1492.

and it is known that solutions of cupric salts are reduced to cuprous salts by boiling with sulphurous acid.* Moreover, sodium thiosulphate added to hot solutions of copper salts gives a black precipitate of cuprous sulphide.† It therefore becomes at once apparent that the precipitating agent in these veins can not have been a soluble sulphide unless there were at the same time a reducing agent strong enough to reduce the cupric sulphate to cuprous sulphate and precipitate cuprous sulphide, and not strong enough to reduce it to native copper.

Literature of Copper Glance

The mineral chalcocite has been formed, both artificially and naturally, in recent times, and is referred to by numerous writers as follows: ‡

Daubrée § found chalcocite crystals accidentally developed on coins and copper instruments which had lain for a long time in damp ground, as at Bourbonnes-les-Bains, Plombieres, etcetera.

De Gouvenain || found crystals of copper glance on fragments of copper which had been for some time in the warm spring of Bourbon-l'Archambault.

Rammelsberg ¶ discovered two small cubical crystals in furnace product from Mansfeld containing iron, nickel, cobalt, zinc, and manganese isomorphous with the copper.

Scheerer ** found small rhombic crystals, supposed to be chalcocite, in a reverberatory furnace at Freiberg.

Mitscherlich †† obtained octahedral chalcocite artificially by melting a proper mixture of copper and sulphur.

Durocher ‡‡ reproduced the rhombic variety by heating in a red-hot tube vapor of copper chloride and sulphuretted hydrogen.

Becquerel §§ obtained copper glance in hexagonal plates by the same method which he employed in the formation of galenite.

Sénarmont |||| obtained only an amorphous precipitate by warming to 200° in a sealed tube a mixture of copper sulphate, bicarbonate of soda, and potassium sulphide.

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* Kohner: Chem. Centralblatt, 1886, 813.

† Vortmann: Monatshefte für Chemie, 1889, 9, 165.

‡ Fouqué and Lévy: Synthèse des Minéraux des Roches, p. 294; M. L. Bourgeois: Reproduction artificielle des minéraux, 1884, p. 38; Meunier: Méthodes de Synthèse en Minéralogie, 1891, pp. 69, 75.

§ Daubrée: Compt. rend., vol. lxxx, 1875, 461.

|| De Gouvenain: Compt. rend., vol. lxxx, 1875, 1297.

¶ Rammelsberg: Metallurgie, p. 224.

** Scheerer: Hütten-Erzeugnisse, p. 366.

†† Mitscherlich: Pogg. Ann., xxviii, 1831, 157.

‡‡ Durocher: Compt. rend., xxxii, 1851, 825.

§§ Becquerel: Compt. rend., xxxii, 1852, 38.

|||| Sénarmont: Ann. ph. ch., xxxii, 1851, 129.

Copper heated to 200° in a closed vessel, in presence of a solution of sulphurous acid, according to the method of Geitner, did not yield satisfactory results. Under similar conditions, a solution of copper sulphite yielded crystalline scales differing from chalcocite in composition, perhaps covellite.

Margottet * obtained crystallized copper glance by the slow passage of hydrogen charged with sulphur vapors over copper at red heat.

Meunier † speaks of the employment of solid precipitants, saying that the reaction in such cases is slow, and favorable for crystallization, and moreover reproduces conditions frequently found in nature. He thus obtained crystals of cuprite, alunite, copper, cotunnite, and matlockite. He is convinced, as the result of many experiments, that the natural sulphides, in the presence of suitable metallic solutions, reduce the metal dissolved to the metallic state; and instances the coating of gold which is deposited on galena when immersed in auric chloride, and of silver when galena is immersed in nitrate of silver. All the sulphides which he has examined produce similar metallic precipitates.

Chalcocite on Coins

The usual explanation given for the formation of copper glance on coins in spring waters is that it is due to the reducing action of carbon.

In his "Minéralogie de la France," ‡ for example, A. Lacroix, in describing the copper sulphide minerals found incrusting old bronze coins in the springs of Bourbonnes-les-Bains,§ says:

> "The chalcocite formed in thermal springs or in fresh water at the expense of Roman coins is explained by the action on the bronze of soluble sulphides, themselves the product of the reduction of sulphates by organic material."

Organic matter is present in the mine waters of Butte, but is not able to reduce all the ferric sulphate to ferrous sulphate, much less have any appreciable effect on the copper salts.

Artificial Formation of Chalcocite

After considering the geological history and physical structure of these ore deposits, the writer came to the conclusion some three years ago that the copper glance was formed by a chemical reaction between copper sulphate in solution in descending waters and the iron pyrites and other primary sulphide minerals lying below. In order to ascertain the truth or falsity of this theory, laboratory experiments were undertaken by the

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* Margotet: Compt. rend., lxxxv, 1877, 1142.

† Meunier, op. cit., 308.

‡ Vol. ii, p. 515.

§ Daubrée: Annales des Mines, viii, 439, 1875.

writer and carried on by Messrs S. J. Gormly and C. F. Tolman in the laboratories of the Anaconda Copper Mining company.

The first experiments were conducted with a relatively small amount of cupriferous pyrite and a dilute solution of copper sulphate. The results, as reported, show the formation first of SO_2 and then of H_2SO_4; the solution of both copper and iron and the precipitation of the iron as ferric hydrate, and the formation of copper sulphide.

Analyses of the mine waters showed no ferrous salt in the strong "copper water," but disclosed the presence of quantities of cuprous salts, in acid solution.

The experiments repeatedly showed that SO_2 is formed by the action of pyrite and chalcopyrite upon $CuSO_4$, and that the SO_2 reduces some of the copper ions of the $CuSO_4$ to the cuprous form. According to theoretical chemistry, a relatively insoluble compound may be precipitated by very small amounts of a salt containing one of the ions of the insoluble compound, if a large amount of the salt containing the other ion is present. To test this, a solution of copper sulphate was treated with the sulphides of arsenic, lead, copper, iron, zinc, and with pyrite; and in each case copper sulphide was precipitated, proving that these sulphides may precipitate copper sulphides from a solution of a copper salt. It is probable also that the more insoluble the precipitating sulphide, the more concentrated must be the solution of copper sulphate.

To produce a solution containing cuprous ions, the above-mentioned sulphides were treated with a solution of copper sulphate ($CuSO_4$) and SO_2, and precipitates were formed in each instance. An analysis of the precipitate formed by copper sulphide showed a precipitation of 12 per cent of the weight of the original CuS as Cu_2S, indicating the formation of chalcocite under these conditions.

It was not ascertained whether the iron salts will reduce enough copper to form Cu_2S in presence of pyrite or other sulphides, or whether the SO_2 formed by solution of the pyrite and other sulphides is the active agent.

Knowing full well that it might be urged that the formation of a precipitate of a certain chemical composition is quite a different matter from the production of a mineral having the same composition, the experiment now about to be briefly described was undertaken and carried to completion with exceedingly gratifying and satisfactory results.

In a slightly acid solution containing sulphurous anhydride (SO_2) was digested pyrite (FeS_2) at ordinary temperature and pressure for three months. The pyrite taken was ordinary "jig concentrates," about one-fourth of an inch in diameter, from the Parrot concentrator at Butte, and of the following composition:

SO_2	8.30
CaO	Trace
MnO	None
Fe	41.20
Cu	1.50
Zn	0.20
S	48.70
	99.90

Dividing these results by the molecular weights, the molecular constitution is represented as follows:

Fe	0.736
Cu	0.024
Zn	0.003
S	1.522

After standing for three months in an ordinarily well lighted room, inclosed in a sealed jar to exclude the atmosphere, the formerly yellow grains of pyrite were completely plated with a solid coating of a dark blue-black mineral, and so closely resemble grains of solid chalcocite that they can only be distinguished from the latter by breaking them open, while in another jar which stood alongside, similarly sealed and exposed to light and ordinary temperature, containing pyrite and copper sulphate solution (but no SO_2), the grains of pyrite were just as bright and yellow as before they were immersed. Indeed, there has been no visible alteration on the surface of grains which have now been thus immersed in copper sulphate without SO_2 for two years, while in an adjacent jar containing SO_2 there has been formed what appears to be, and undoubtedly is, a fine coating of chalcocite.

From the first jar there were taken some of the larger grains for analyses, with results as follows:

SiO_2	9.60
CaO	....
MnO	....
Fe	40.10
Cu	3.60
Zn	
S	46.30
	99.60

CaO, MnO, and Zn not determined.

The molecular constitution is now Fe, 0.716; Cu, 0.057, and S, 1.448. There are .016 equivalents of sulphur left over (after calculating the iron as FeS_2) to unite with the copper. The exact theoretical amount to form Cu_2S is .014, and the surplus sulphur may be combined with zinc,

lime, or manganese. That the mineral coating thus formed on the jig-concentrates is clearly chalcocite can not be doubted from a mere inspection of the samples and comparison with ore from the mines.

Chemistry of Oxidation of Pyrite

The chemical changes involved in the oxidation of pyrite have been discussed by S. H. Emmons* and by Penrose,† and more recently by Van Hise, Weed, Emmons, and others, and the equations given indicate the formation of sulphur and sulphurous anhydride as a product of such oxidation.

The real agency of this SO_2 and its probable role as an active reducing agent, capable, for example, of reducing cupric sulphate to cuprous sulphate preparatory to its deposition as cuprous sulphide, seems to have been overlooked. The equations given by Emmons are as follows:

"1. $FeS_2 + O_3 + H_2O = FeS + H_2SO_4$.
2. $FeS + H_2SO_4 = FeSO_4 + H_2S$.
3. $FeS_2 + O + 2H_2S = FeS + 2H_2O + 3S$.
4. $S + O_2 + H_2O = H_2SO_4$.

That is to say, the oxygen of the atmosphere and the moisture of the ground and air convert part of the sulphur into sulphuric acid and leave a residue of iron monosulphide, which is then attacked by the sulphuric acid with formation of ferrous sulphate and evolution of sulphuretted hydrogen. This latter reacts with the sulphurous anhydride formed (together with sulphuric acid) by the oxidation of the sulphur in the marcasite, and produces water and free sulphur, the latter of which is in its turn oxidized and produces a further quantity of sulphuric acid, and so on. Hence, as the result of the first attack on the ores we should expect to find ferrous sulphate, sulphuretted hydrogen, free sulphur, and surphuric acid.

Now, a solution of ferrous sulphate eagerly absorbs atmospheric oxygen and sulphuric acid to form ferric sulphate, thus,

$$2FeSO_4 + O + H_2SO_4 = Fe_2(SO_4)_3 + H_2O,$$

and therefore, although I have spoken of ferrous sulphate and free sulphuric acid as amongst the first results of the gossan-forming action, they are rapidly converted into a solution of ferric sulphate; and it is in this latter form that they are usually found in mine-waters and the like. In some cases, however, where local circumstances impede peroxidation, ferrous sulphate remains in considerable quantity, as, for example, in the manufacture of copper by exposing large heaps of pyrite to the action of the atmosphere and moisture.

Let us next consider what will be the action of the ferric sulphate upon the remaining ferrous sulphide. This is shown by the following equation:

$$FeS + Fe_2(SO_4)_3 = 3FeSO_4 + S;$$

or, in other words, one molecule of ferric sulphate will abstract one molecule of iron from ferrous sulphide, forming 3 molecules of ferrous sulphate and setting free the sulphur."

* Engineering and Mining Journal, Dec. 17, 1892, p. 582.
† Journal of Geology, 1894, pp. 288–317.

The essential part of these operations may be expressed in a condensed form as follows:

1. $FeS_2 + H_2O + 6O = FeSO_4 + SO_2 + H_2O$.

The SO_2 perhaps aided by the ferrous sulphate, reduces a portion of the copper, as follows:

2. $2CuSO_4 + SO_2 + 2H_2O = Cu_2SO_4 + 2H_2SO_4$.

The acid solution would perhaps form H_2S by attacking the pyrite; and CuS would be formed, except for the presence of the SO_2, which holds the copper in the form of cuprous sulphate and makes the precipitate cuprous sulphide; or, if H_2S be not formed by the acid present, and if the Cu_2S is more insoluble than FeS_2, there would be a precipitation of Cu_2S and a solution of iron as sulphate.

3. $FeS_2 + H_2SO_4 = FeSO_4 + H_2S + S$.

4. $Cu_2SO_4 + FeS_2 = FeSO_4 + Cu_2S + S$.

In nature, the oxidation of pyrite sometimes leaves residual sulphur, but usually the sulphur is oxidized and again taken into solution.

Chalcocite a secondary Mineral and primary Ore

It will be observed that the solutions here employed are all acid solutions and contain no alkaline carbonates. This corresponds with the conditions existing in the Butte mines now and for a long period since the flows of ascending waters ceased and the work of oxidation and erosion began. It seems probable that the waters which have thus deposited chalcocite as a secondary mineral have in most cases been acid waters, and that their movement has been downward. It does not necessarily follow, however, that chalcocite can not be formed in any other way; in fact it is quite possible that ascending alkaline solutions containing copper might deposit chalcocite as a primary ore. In that event we should almost certainly find hematite formed as an associated mineral. Indeed this oxide of iron has been reported from some mines under conditions precluding the supposition of origin through the action of descending waters. No hematite, however, is found in the lower levels of Butte mines, nor have alkaline carbonates been found in considerable quantity.

At many points in the Butte mines are found ores precisely similar in appearance to those thus produced synthetically. Frequently these ores, at first supposed to be pure chalcocite, on analysis prove to be low grade, and on breaking disclose an interior of solid pyrite and a mere surface film of copper glance. So far as I am aware, this is the first account of the synthesis of chalcocite in the wet way, and the first time it has been experimentally demonstrated that important sulphide ore deposits are enriched far below the surface of the ground water by reaction between oxidized solutions from and above the original sulphides.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 14, PP. 277-296 AUGUST 5, 1903

GEOGRAPHIC DEVELOPMENT OF NORTHERN PENNSYLVANIA AND SOUTHERN NEW YORK*

BY MARIUS R. CAMPBELL

(*Read before the Society December 30, 1902*)

CONTENTS

Introduction

The surface features of northern Pennsylvania and southern New York consist in a broad way of an elevated plateau so extensively dissected that only small remnants remain here and there of what appears to have been once a fairly even surface. Although this country is readily accessible, and is familiar to many of our leading physiographers, no attempt so far has been made to unravel its physiographic history. Beyond a brief reference by Davis † and Tarr ‡ of the surface of this plateau to the Cretaceous peneplain, nothing has been done in the way

*Published by permission of the Director of the U. S. Geological Survey.

† The geologic dates of origin of certain topographic forms on the Atlantic slope of the United States. Bull. Geol. Soc. Am., vol. 2, p. 566.

‡ Physical geography of New York state, p. 102.

of establishing the dates of origin of the topographic features of the region. Doubtless this lack of attention in the past was due to the absence of adequate maps, but in a large measure these are being supplied, and now it is possible, by the aid of the topographic sheets at hand, to study the surface features of the region and provisionally to correlate them with similar features of known age in other parts of the country.

Description of the Region

One of the best regions for physiographic study is embraced in the Tioga, Elkland, and Gaines quadrangles in Tioga and Potter counties, Pennsylvania. Erosive conditions in this region presumably have been similar to those prevailing over most of the plateau in question, and consequently the topography may be regarded as the type of the region. A careful study of this topography shows that the descriptions already given of the topographic features are not quite correct, and that instead of being simply a deeply dissected plateau surface it really consists of a dissected plateau upon which stand distinctly higher ridges with comparatively flat tops. It seems probable, therefore, that the physiographic history of the region is complex and similar to that which has prevailed in the eastern part of the state.

The rocks composing the plateau region of northern Pennsylvania and southern New York are fairly homogeneous. The formations involved are those which constitute the upper part of the Devonian and the lower part of the Carboniferous series. In a general way the rocks may be divided into two classes, which differ in their hardness and in their resistance to the action of erosion. The softer rocks belong to the Chemung formation; they are shaly and somewhat calcareous, and consequently are reduced with comparative ease. Above the Chemung rocks occur the more sandy Catskill-Pocono beds and also the very resistant sandstones of the Pottsville formation. The softer Chemung beds are exposed in outcrop on all the anticlines of the region, and the harder beds overlying them are present in all of the synclinal troughs.

Although deeply dissected, the Chemung hilltops on the anticlinal tracts have remarkable uniformity in altitude—a fact which at once suggests a dissected peneplain. Not only do the hilltops of one anticlinal region rise to a common height, but there is an agreement between the upland surface of adjacent anticlines to such an extent that it seems impossible to avoid the conclusion that they are parts of one extended peneplain which was developed on the softer rocks of the region. This supposition is also borne out by the character of the hilltops, which are generally rounded and in many cases are almost absolutely flat.

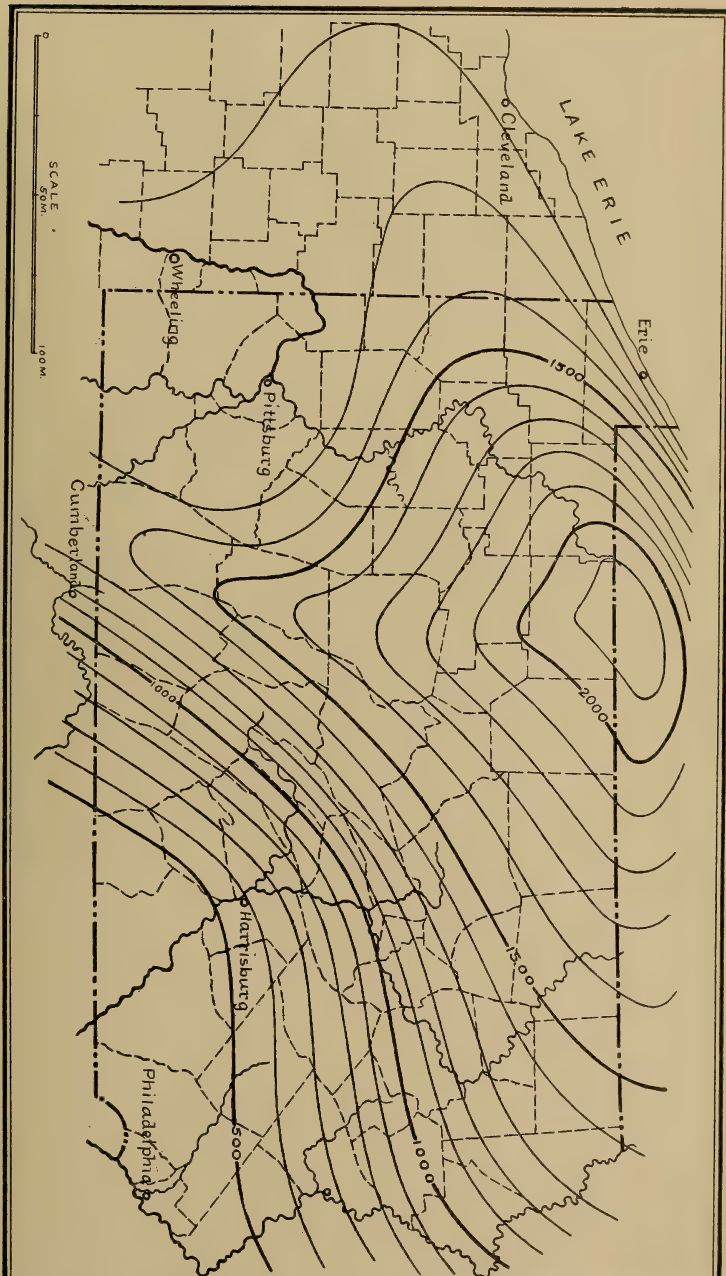

FIGURE 1.—*Map showing warped Surface of Harrisburg (Early Tertiary) Peneplain*

Contour interval, 100 feet

In the region mentioned this surface may be observed in the southeast corner of the Tioga quadrangle, in the vicinity of Mansfield, at an altitude of about 1,600 feet. In the northeast corner of the same quadrangle it rises to about 1,800 feet. In passing westward it is found at an altitude of 1,800 or 1,900 feet in the northern part of the Elkland quadrangle, and still farther west it rises to an altitude of 2,100 or 2,200 feet in the northern part of the Gaines quadrangle on the New York state line. Part of this increase in altitude toward the west may be due to the greater distance from the main drainage lines, but evidence presented later makes it seem probable that all of the surface features of this region show a similar rise toward the west, and that it is largely due to crustal movements.

The area under discussion is crossed by a broad synclinal trough, which extends from the southwest corner of the Gaines quadrangle to the middle of the eastern side of the Tioga quadrangle. Although breached by streams in many places, this is a fairly continuous ridge, which rises 400 or 500 feet above the Chemung uplands on the adjacent anticlinal tracts. The general altitude of this ridge at the eastern margin of the territory is about 2,200 feet. It rises gradually westward to 2,300 feet on the western margin of the Elkland quadrangle and 2,400 or 2,500 feet on the western edge of the Gaines quadrangle. In the center of this trough the rocks are nearly horizontal, and the resulting topography is characterized by broad and flat-topped summits. If the ridge throughout this territory were capped continuously by the heavy Pottsville conglomerate, such flat tops would not be surprising; but the synclinal trough consists of a series of connected basins, in which the Pottsville rocks are preserved, but between which the surface of the ridge is composed only of the thin-bedded Catskill-Pocono rocks. In their resistance to erosion these beds bear no comparison to the massive Pottsville sandstones, but despite this difference the surface of the ridge where they outcrop is practically at the same elevation as in the localities where it is composed of the Pottsville sandstone. For this reason it seems probable that the summit of this ridge is also a remnant of a peneplain which is much older than that at the level of the hilltops on the adjacent anticlinal tracts.

Although remnants of two peneplains may be easily distinguished in this region, the determination of their dates of origin is a difficult question. As heretofore mentioned, this general upland surface has been referred to the Cretaceous peneplain; but from the foregoing facts it is apparent that the surface features are not so simple as has been supposed, and consequently there may be two peneplains to account for instead of one. Since it is not possible at the present time to trace these

features eastward and correlate them definitely with those whose dates of origin have been well determined, it is necessary to depend largely on the characters which these forms possess. In entering on such a study it is well to bear in mind that the region has been glaciated, that the hilltops have been abraded to a certain extent by the ice-sheet, and that the valleys suffered a large amount of filling from the same source; but the region in question is near the outermost margin of the glacial ice, and it was not seriously affected by the abrading action. Although the topography has been slightly modified, it has not been changed in its essential characteristics, and hence we may safely compare the surface features here shown with those of other regions whose dates of origin are fairly well determined.

Interpretation of Surface Features

Although the writer began the study of this region with the impression that the surface features are very old, he was soon impressed with the fact that the hilltops composing the lower peneplain are distinctly rounded, and in many places flat—features which are not characteristic of extreme age. The drainage of the region also is incomplete and the dissection has not advanced to that stage which characterizes the Cretaceous peneplain in other parts of the country. In studying its topography the writer has instinctively compared it with the Coal Measures plateau of the central Appalachian region. This plateau is generally regarded as being of Cretaceous age, and hence there should be a similarity between the two features, if the plateau of northern Pennsylvania and southern New York is of the same age. The Appalachian plateau is composed of harder rocks than the Chemung formation, and consequently if the two features are of the same age the plateau character should be better preserved in the central Appalachian region than in northern Pennsylvania, but a comparison of the topographic map of the two regions shows at a glance that dissection is much more complete in the Appalachian region than in northern Pennsylvania. In the former locality the hilltops are rudely conical and no flat land remains to mark the former surface of the peneplain. In the New York region, as heretofore shown, the hilltops are gently rounded and in many cases flat, and presumably such tops are direct remnants of the peneplain surface. The conclusion, therefore, seems inevitable that the peneplain formed upon the Chemung rocks of northern Pennsylvania and southern New York is much younger than that which marks the surface of the Coal Measure plateau in the central Appalachian region. From this evidence it seemed to the writer probable that the Jura-Cretaceous peneplain may

be represented by the synclinal ridges, which in this region rise to altitudes ranging from 2,200 to 2,500 feet, and that the Chemung hilltops, which vary from 1,600 to 2,200 feet, may represent a peneplain of early Tertiary age.

Similar conclusions were arrived at independently by Mr L. C. Glenn in the study of the Olean and Salamanca quadrangles of southern New York. Although in this region the hilltops vary more in altitude than in Tioga county, Pennsylvania, a close study reveals the fact that those which lie at an altitude of about 2,100 feet in the northern part of the quadrangles have very flat summits, while those which rise to higher elevations are irregular and have very little flat or gently rolling land upon their crests. Mr Glenn is disposed to regard the 2,100-foot contour as marking approximately the position of a Tertiary peneplain surface, while the flat tops along the state line, made by the massive Olean conglomerate at an altitude of about 2,400 feet, presumably represent the peneplain of Jura-Cretaceous age.

Physiographic Features of eastern Pennsylvania

Inasmuch as the present interpretation of the physiographic history of the plateau region is different from that heretofore maintained, it seems advisable to review briefly the topographic features of the eastern part of Pennsylvania to see whether previously they have not been misinterpreted and whether a new interpretation may not be made that will be in agreement with the writer's conclusions regarding the succession of events in the plateau region.

The only publications dealing with the physiography of this district are the papers by Davis on "The rivers and valleys of Pennsylvania" * and Davis and Wood on "The geographic development of northern New Jersey." † In these papers Davis recognizes the remnants of two peneplains—one represented by the even crest-lines of the valley ridges and presumably of Jura-Crustaceous age and the other of late Tertiary date and developed only on the soft rocks of the Kittatinny valley and on the wide outcrop of Newark rocks which forms a belt of lowland across the two states.

With these two propositions the writer is in entire accord; therefore it is unnecessary to review the evidence on which they are based; but the point of difference is the recognition by the writer of a peneplain lying between those described by Davis, which is less extensive than the Schooley (Jura-Cretaceous) and much better developed than the

* National Geographic Magazine, vol. i, pp. 184–253.

† Boston Society of Natural History, Proceedings, vol. 24, pp. 365–423.

late Tertiary or Somerville plain, and which presumably was produced in the early stages of the Tertiary epoch.

Somerville Peneplain

According to Davis, this peneplain was developed only on the weakest rocks of the region. It is best preserved in the area of Newark rocks about Somerville, New Jersey, and consequently derives its name from that point. Along this belt Davis recognized the peneplain across New Jersey and into Pennsylvania. He also identified it in the Kittatinny or Lebanon valley, where it is developed on the softer part of the Cambro-Silurian limestone along the Delaware and Lehigh rivers. Its present altitude in this locality ranges from 350 to 400 feet. The time during which the crust of the earth remained stationary appears to have been too short to permit of the reduction of the limestone in the interstream areas, for in passing to the west of Allentown the low valley disappears, and the land rises to an altitude of 500 feet in a distance of 15 miles.

On the Susquehanna river this peneplain seems to have a wide development on the limestone, in the vicinity of Lancaster at an altitude of about 350 feet and below Harrisburg at an altitude of 400 feet. On the Potomac river it is probably present in the vicinity of Harpers Ferry at an altitude of 500 feet.

Harrisburg Peneplain

SHENANDOAH VALLEY

Throughout the great valley which locally bears the names Shenandoah, Lebanon, and Kittatinny, there are two wide bands of outcropping rocks of different characteristics, and consequently possessing different degrees of resistance to erosion. The rocks on the southeastern side of the valley are easily eroded limestones, and on these soft rocks the Somerville plain, as previously described, is developed in the vicinity of the larger streams. The rocks on the opposite side of the valley are shales of the Hudson formation, and they possess a moderate amount of resistance to erosive agencies. As a result of their composition they are not reduced to the level of the limestone part of the valley, but stand distinctly above it as a sort of hilly upland. Such a relation of the surfaces found on rocks of different degrees of resistance is not surprising. Indeed, it is perfectly normal, and should occur in any partial cycle of erosion; but when the hill country is examined more in detail, it is found to be remarkably uniform in altitude, and it is this feature which calls for a special explanation. The regularity of the hilltops along this

belt is such that it was recognized by Lesley,* who described it as follows:

"It (the shale belt) is a region of low, flat-topped hills, trenched by a multitude of small valleys, and, when looked down upon from the mountain, appears like a great plain, which it really is."

Since in a broad way the surface of the shale belt resembles a plain, but in detail is irregular, it may be regarded as a peneplain, and for convenience in discussion the writer designates it the Harrisburg peneplain from its development near the capital of the state.

DELAWARE VALLEY

The Harrisburg peneplain is well developed in the vicinity of the Delaware river, and since this is one of the localities mentioned by Davis, in which the Somerville plain is well shown, it will be described in considerable detail.

As previously mentioned, the limestone part of the valley from Belvedere to Allentown is reduced to a fairly uniform surface, having an altitude of from 350 to 400 feet. This valley is bounded on the southeast by irregular ridges of Archean rocks, which do not appear to have been reduced to any particular level. On the northwest the valley floor representing the Somerville plain is bounded by a belt of hilly country from 10 to 12 miles in breadth, developed on the somewhat resistant shales of the Hudson epoch. Although the line separating these two topographic features is not so distinct as that which bounds the limestone valley on the southeast, still, in a general way, the shale hills stand sharp and distinct above the surface of the Somerville plain. Fortunately the Slatington quadrangle, which includes the western part of the area under discussion, recently has been carefully mapped, and a study of this atlas sheet shows clearly the character of the topography developed on the shale belt. The map shows almost no level land in this area, but, what is more important, it shows great regularity in the heights of the hilltops over most of the region. True there is a range in altitude from 600 to 900 feet above sealevel, but the hills, which rise to 800 or 900 feet, are few in number and generally isolated, and it is apparent that they rise above what may be called the general platform of the shale belt. They are residuals composed of harder rock which have more successfully withstood erosion than the surrounding region, or they occur in sheltered localities away from the main drainage lines, and so have been preserved from the general degradation of the region. The tops, which stand at an altitude of 600 feet, are on points projecting into

*General Introduction to Report D 3, p. 27.

the valley or in close proximity to the major drainage lines, and so have been exposed more severely to erosion than the more protected localities, and consequently are reduced below the general upland surface. From these facts it seems probable that the general platform on which the higher knobs stand and from which the projecting spurs were reduced has an altitude of about 700 feet.

The production of such a platform might easily be accounted for if the geologic structure of the region were simple and the top of the platform corresponded in position with a particularly hard bed of the series. But, generally, the rocks are greatly crushed and crumpled and the surface of the platform as described above cuts these beds at all angles from 90 degrees to 0. Manifestly it is impossible to explain the existence of this surface by the effect of the underlying rocks on the erosion of the region.

Although the surface of the shale belt is far from flat, there is such a general correspondence in altitude that it seems to the writer that it must be regarded as the result of subaerial erosion when the land in this locality stood nearly 700 feet lower than it does at the present time. From the nature of the material on which this topographic feature is developed, it is probable that a plain would not be formed except under the most favorable conditions of long-continued and uninterrupted erosion. The erosion period which resulted in the formation of this feature was evidently a partial cycle only in which the harder rocks of Blue mountain on the northwest and the Archean ridges on the southeast were not materially affected, but the softer rocks were well reduced, resulting in a rolling or somewhat hilly surface on the outcrop of the shales and probably a nearly perfect plain at about the same level on the outcrop of the Cambro-Silurian limestone. Along the limestone belt the plain has been dissected and generally removed in subsequent periods of erosion, and during one of these short sub-cycles the Somerville plain was produced at a considerably lower level.

Lesley * recognized these two distinct surfaces, and it is interesting to note that while regarding them as products of subaerial erosion, he attributes the low altitude of the limestone area solely to the greater activity of chemical erosion. He speaks of the features as follows :

> "The old idea that the land surfaces have been produced by sea waves has been discarded; and with regard to the two plains of Northampton county, composing side by side the floor of the great Kittatinny valley, but the one 200 feet higher than the other, it is evident that the ocean has had no hand in their formation."

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* Op. cit., p. 37.

In a recent description of the topography of the slate belts of Lehigh county, Dale* recognizes the upper peneplain, but he makes no effort to determine its extent or its date of origin.

It seems to the writer, therefore, that there is undoubted evidence of the existence of a peneplain other than the Somerville or Schooley, and also that the newly recognized peneplain lies about 300 feet above the Somerville plain, and consequently is a much older feature.

SCHUYLKILL VALLEY

In passing to the southwest these two features are easily recognized along the Schuylkill river in the vicinity of Reading. The limestone belt is narrow at this point, and consequently the lower plain is not extensively developed, but it is present at an altitude of about 300 feet above sealevel. The Hudson shale has an extensive geographic development northwest of Reading, and fortunately there is an excellent contour map from which to study the character and altitude of the surface. On the Wernersville quadrangle the country lying north of the narrow valley contains scarcely any level land. It is made up entirely of small hills, which, as a rule, stand at an altitude of about 500 feet above sealevel. Where harder rocks occur, the hills stand up as monadnocks above this common level to altitudes as high as 800 feet, but these are clearly above the general hilltop level. The line of demarkation between the monadnocks and the surface of the peneplain is well shown west of Bernville, where a small ridge rises abruptly from a platform at about the 500-foot contour. When it is considered that the rocks of this belt are considerably disturbed, and that they consist of a heterogeneous mass of shales, it is impossible to account for the regularity of the hilltops on any other hypothesis than that of baseleveling.

SUSQUEHANNA VALLEY

West of the Wernersville quadrangle the valley has not been mapped with sufficient care to bring out the details of the surface features, but in the Lebanon quadrangle the surface of the shale belt appears to range from 500 to 600 feet above sealevel. The Somerville plain is not represented in this region, either on account of the hardness of the limestone or of the distance from the major drainage lines; but it is well developed on the southern belt of limestone in the vicinity of Lancaster at an altitude of about 350 feet. Similar features show in the Hummellstown quadrangle, the Somerville plain being slightly developed along Swatara creek. The surface of the shale belt on the north side of the valley

*Slatington folio, U. S. Geol. Survey. In press.

shows a general correspondence in altitude, the hills rising to levels which range from 500 to 600 feet above sealevel.

The meanders of Swatara creek seem to afford evidence of a widely developed peneplain in late geologic time, which extended not only over the limestone belt on the southern side of the valley, but also over the shale belt on its northwestern side. It does not seem possible for these meanders to date back to the formation of the Cretaceous peneplain, for in the immensely long time that has elapsed since the formation of that peneplain the creek should have adjusted itself to the outcrop of the hard and soft rocks, and should have found a resting place on the south side of the valley. An inspection of the map shows that such is not the case, and that the stream flows indifferently on shales and limestones. The same argument may be used for Conodoguinet creek which has developed such extensive meanders on the shale belt west of Harrisburg. Meanders of this kind could have been developed only on a well reduced peneplain, and if, as pointed out previously, they could not have persisted since early Cretaceous time, they afford strong evidence of the existence of an extensive and well developed plain since that date. Hence the peneplain on which these meanders were formed is of more recent date than the Schooley peneplain, and it is older and more extensive than the Somerville plain; therefore it seems to agree perfectly with the Harrisburg peneplain as here defined.

The shale hills in the vicinity of Harrisburg, as shown on the atlas sheet, show remarkable regularity at an altitude of about 500 feet. The Somerville plain is not well developed in this region, but there are wide stream valleys on the quadrangle at an altitude of about 400 feet, which presumably were formed in this cycle. These agree very well with the lowland about Reading, and presumably they are the southwestward representatives of the same feature. It can not, however, be followed continuously to the southwest, as the surface of the limestone belts soon rises to practically the same level as the shale hills on the northwestern side of the valley.

On account of the lack of maps the Harrisburg peneplain can not at present be traced to the Maryland line, but it shows at an altitude of 500 feet in the northwest corner of the Carlisle quadrangle, where it appears to have been as well developed as in the type locality. It also shows in the belt of shale hills lying west of Chambersburg, which have remarkably level tops, at an altitude of a little over 700 feet. The Somerville plain also seems to be developed in this region along Conococheague creek at an altitude of 550 to 600 feet.

From the above facts, it seems evident that the Somerville and Harrisburg peneplains approach each other toward the southwest. Along

the belt just described the interval between them varies from 300 feet at Easton to a little over 100 feet near the Maryland state line. On account of this convergence the two features are not so easily differentiated in the Potomac valley as they are in the Delaware or Susquehanna valleys. In fact, along Conococheague creek the post-Harrisburg uplift was so slight that the deeply weathered surface of the Harrisburg peneplain on the shale belt was reduced practically to the same level as the adjacent limestone valleys.

POTOMAC VALLEY

The topographic maps recently prepared of the territory along the Potomac river show admirably the character of the Harrisburg peneplain. In the Hancock quadrangle the rocks are sandy shale, belonging to the Devonian period. A casual inspection of the map shows that it is an extremely hilly country, but upon closer examination it is found that the hilltops show great regularity in altitudes, ranging from 600 or 700 feet in the southeastern corner to about 800 feet in the northwestern corner of the quadrangle. If the irregularities due to recent erosion were eliminated by filling the sharp V-shaped stream valleys to the heights mentioned, the surface would be very regular, and certainly would be classed as a peneplain. It is interrupted here and there by monadnocks which stand above the general level, but in all such cases the monadnocks represent harder rocks than the average and their presence tends to confirm the idea that the surface is a peneplain and due to subaerial erosion. The geologic structure of the region consists generally of broad, open folds, with many minor wrinkles to complicate the structure. The planes of stratification are generally inclined, and the peneplain, which is represented by the tops of the hills, cuts across the beds of rock at all angles. It seems impossible to account for this general accordance in altitude on any other theory than that of peneplanation.

Unfortunately there is no detailed map of the Shenandoah valley by which to compare the topography of the shale belt with that developed on the limestone belt to the east. If, however, the Harpers Ferry map is consulted, it will be seen that the valley floor is gently rolling and it ranges in altitude from a little less than 500 feet near the major drainage lines to about 600 feet on the shale belt in the central part of the valley. Keith * endeavored to account for this variation in the floor of the valley on the supposition that it represents incomplete reduction to a baselevel, which presumably now stands at an altitude of 500 feet. This is probably true as far as it goes, but it seems probable that the

* Geology of the Catoctin belt, U. S. Geol. Survey, Fourteenth Annual Report, pp. 374–376.

peneplain recognized by Keith is the Somerville plain, and that he failed to appreciate the fact that the highest land in the valley corresponds in altitude with the general surface of the shale hills to the north, and therefore in all probability is a remnant of the Harrisburg peneplain.

Abbe,* in his study of the surface features of Maryland, recognized the Harrisburg peneplain in the shale belt of the Hancock quadrangle, and he traced it west as far as Cumberland, at the foot of the Allegheny Front, but in attempting to extend it to the east he apparently has confused it with the Somerville plain, which occurs at least 100 feet lower than the Harrisburg peneplain. Abbe gives its altitude across the limestone belt of the valley as 600 feet, on both the Potomac river and Conococheague creek, but he failed to observe that just north of the state line the two peneplains are well developed in the vicinity of Chambersburg, Pennsylvania, with a vertical interval between them of at least 100 feet.

Thus it seems probable that the Harrisburg peneplain stands at an altitude of 700 feet in the southeast corner of the Hancock quadrangle, 600 feet in the shale belt west of Harpers Ferry, and 500 feet in the eastern part of the Harpers Ferry quadrangle.

The deposits of gravel which Keith † regards as belonging to the Lafayette formation presumably lie upon remnants of the Harrisburg peneplain, and their presence affords corroborative evidence regarding the early Tertiary age of this topographic feature.

UPPER POTOMAC VALLEY

In passing west from the Hancock quadrangle the surface is seen to become more rugged, the rocks are composed of harder material, and the reduction was evidently not so complete as farther east. There are, however, belts of weak rocks showing in the Pawpaw quadrangle, on which the Harrisburg peneplain was fairly well developed. In the eastern part of the quadrangle it has a general altitude of about 800 feet, and on the western side about 900 feet above sea-level. In the Flintstone quadrangle the rocks are of such a character that the reduction was not very complete, but the general surface on the softer rocks seems to correspond on the eastern side with the 900-foot level observed in the quadrangle to the east. In the vicinity of Cumberland the evidence is not so conclusive regarding the altitude of this plateau, but along a belt of weak rocks in the southeastern corner of the Frostburg quadrangle the altitude of the hills does not exceed 1,200 feet. This is taken provisionally as

* Physiography of Maryland, Maryland Weather Service, vol. 1, part 2, pp. 157–161.

† Op. cit., pp. 366–369.

representing the altitude of the peneplain. This determination is, in a measure, corroborated by the altitude of an abandoned water gap through Wills mountain, just west of Cumberland. While such features as this can not be regarded as positive evidence of the existence of a peneplain, still it seems probable that the abandonment of this gap occurred after a period of baseleveling, when the streams were revived and erosion was most active.* The altitude, therefore, of the Harrisburg peneplain in the vicinity of Cumberland is probably about 1,200 feet.

From the above figures it is seen that this peneplain has a decided eastward slope from Cumberland to Harpers Ferry, and while it is certain that some of the slope is original and due to the grade of the stream while the peneplain was forming, it is probable that at least 90 per cent is due to subsequent deformation.

The Shenandoah Valley plain, which is so well developed about Harpers Ferry, with difficulty can be traced up the Potomac to Cumberland. Since it is a feature which is developed only on the softest rocks of the region, it is not reasonable to expect any extended development on the hard rocks which characterize the Potomac valley in this region, but in a few places in the immediate vicinity of the river where drainage conditions were most favorable, there are traces of a lower level which presumably corresponds with the Shenandoah plain. Its altitude can not be definitely fixed, but in the vicinity of Cumberland it appears to range from 700 to 800 feet. Since the two surfaces are separated by about 100 feet at Harpers Ferry and 400 to 500 feet in the vicinity of Cumberland, it is apparent that considerable deformation ensued after the development of the Harrisburg peneplain and before the formation of the Somerville plain. As a consequence of this deformation the two surfaces diverge toward the northwest and converge toward the southeast, and it is probable that they coincide somewhere between Harpers Ferry and Washington.

UPPER SUSQUEHANNA VALLEY

Along the Susquehanna river the Harrisburg peneplain is fairly well developed and shows features similar to those observed along the Potomac river. From an altitude of 500 feet at Harrisburg it rises steadily upstream to about 600 feet in the northern part of the Harrisburg quadrangle, and to 800 feet in the vicinity of Sunbury. From this point it can be traced up the main river to an altitude of from 1,200 to 1,300 feet in the vicinity of Pittston, where it shows a remarkable development on the Devonian shale hills west of the river. The valley in which the

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*Abbe: Op. cit., p. 160.

Susquehanna flows has an altitude at this point of about 600 feet. It is bordered on the west by a low ridge of Pottsville sandstone which rises to an altitude of 1,500 or 1,600 feet; behind this, and stretching to the northwest for a distance of 10 miles, is a belt of Lower Carboniferous and Devonian shales which have a remarkably regular surface altitude of from 1,200 to 1,300 feet. It is true that the region is extremely hilly and that many knobs rise above the general level, but when it is considered that the region lies at a considerable distance from the sea it is surprising that it should be reduced to so uniform a level. This hilly region is bounded on the northwest by the Pocono plateau, which rises abruptly to an altitude of from 2,200 to 2,400 feet. The differentiation of these features is extremely sharp, and it seems impossible to explain the intermediate plateau on any other supposition than that it once stood near baselevel and was subject to uninterrupted erosion through a long period of time. The adjacent regions show traces of the same surface, but at no other place is it so well developed as in this particular locality.

The Juniata valley has not been completely mapped, and therefore it is impossible to trace continuously the peneplain in that direction; but recently some excellent maps have been made of its headwaters, which show features similar to those just described. In the great Nittany valley at the head of the stream, the limestones have been reduced to a fairly even surface at an altitude of from 1,200 to 1,400 feet. The Devonian shales in the same region have suffered similar reduction, so that it seems probable that the Harrisburg peneplain was developed in the vicinity of Hollidaysburg and Altoona.

The Somerville plain of Professor Davis seems to show at intervals along the Susquehanna river, rising from an altitude of 400 feet in the vicinity of Harrisburg to possibly 700 feet at Pittston. Above this point it does not appear in the harder rocks of the Allegheny plateau. Simiiarly up the Juniata river it seems possible to trace it to above Hollidaysburg at an altitude of about 900 feet. Thus it appears that this region suffered an amount of deformation similar to that of the Potomac valley in middle Tertiary time, and that since the development of the Somerville plain it has suffered deformation along an axis presumably corresponding with or west of the Allegheny front.

From the above review of the evidence in eastern Pennsylvania it seems to the writer that the Harrisburg peneplain must be recognized as the most important topographic feature of Tertiary time, and that it represents an extremely long period of undisturbed erosion. The Somerville plain, which is so well exposed on the weak rocks in the eastern part of

the state, is by comparison an insignificant feature and represents a very short and partial cycle of erosion.

OHIO VALLEY

Throughout southeastern Pennsylvania the conditions are favorable for the extensive development of the Harrisburg peneplain, and at least along the main drainage lines it can be identified with a fair degree of certainty as far to the northwest as the Allegheny front. West of this line the rocks are more resistant, and it can be traced with difficulty. Moreover the Allegheny front, in a general way, constitutes the divide between the streams flowing directly into the Atlantic and those flowing into the Mississippi valley, and it is doubtful whether this divide was reduced during the Harrisburg cycle. The Susquehanna and Delaware rivers are exceptions, but the gorges which they have cut in the eastern part of the plateau are through hard and fairly homogeneous rocks, and it is probable that the Tertiary peneplain was not developed in this region. The absence of accurate topographic maps has heretofore made it impossible to correlate the Tertiary features of the eastern part of the state with those west of the Allegheny front, but within the last three years a large area has been mapped in the western part of the state and the topography has been studied carefully, so that now it seems possible to interpret the surface features of that part of the state as accurately as has been done with those east of the Allegheny front.

The feature equivalent to the Harrisburg peneplain is probably best shown in the Monongahela valley.* From Pittsburg to the West Virginia line the rocks are composed largely of limestones and calcareous shales which were fairly well reduced during the early Tertiary period of erosion. This is shown in the Brownsville, Masontown, Connellsville, and Uniontown atlas sheets. In this region the surface was not a perfect plain, but the inequalities were slight and the view today from one of the ridges rising to the altitude of this old surface is that of a very gently undulating plain which in the distance produces an almost even and horizontal skyline. The altitude of the surface is now about 1,250 feet. The peneplain seems to have been produced only where erosion conditions were most favorable and the strata were soft and easily eroded.

The date of origin of this feature can not be determined definitely, but it is well developed up to the foot of Chestnut ridge, which is the westernmost outlier of the mountainous region of this part of the state. Chest-

*See description in the Masontown-Uniontown folio, No. 82, of the Geologic Atlas of the United States; also in the Brownsville-Connellsville folio, now in press.

nut ridge is composed of hard rocks, and rises to an altitude of from 2,400 to 2,600 feet above sealevel. Its summit is not level like many of the ridges of the eastern part of the state, but it is probable that in a general way it is a remnant of the Cretaceous peneplain. If this is true, then it is altogether probable that the peneplain below, or that which has been described as standing at an altitude of 1,250 feet, is of early Tertiary age, and consequently corresponds with the Harrisburg peneplain of the eastern part of the state. This correlation is strengthened by the correspondence in altitude of the peneplain on the two sides of the mountainous region. On the east it has been traced up the Potomac river from an altitude of 500 feet at Harpers Ferry to 1,200 feet at Cumberland, and although the Monongahela valley is about 50 miles west of Cumberland and separated from it by a mountainous region which was not reduced during the formation of the Harrisburg plain, it seems probable that the projection of this surface would rise somewhat west of Cumberland, and then descend slightly to the Monongahela valley corresponding with the surface already recognized at an altitude of 1,250 feet.

Thus the correlation of the peneplain showing in the Monongahela valley with the Harrisburg plain is based on the similarity of the two features, on the association of surface forms, and the correspondence in altitude along the southern border of the State.

The peneplain of the Monongahela valley can be traced down that stream to Pittsburg, and from that point to the west along the Ohio river for an indefinite distance. It is well developed at the mouth of Beaver river at an altitude of about 1,200 feet, as shown on the topographic map of the Beaver quadrangle. From this point it can be traced into Ohio, where it has a wide development from Cleveland on the north at least as far as Steubenville on the south. It may be seen on the Cleveland, Wooster, Massillon, Canton, Wellsville, Cadiz, and Steubenville atlas sheets.

In the southwestern corner of Pennsylvania and in the adjacent parts of West Virginia no trace of this peneplain has been observed. The surface of the upland is higher than in the adjacent regions on the east, north, and west. The crests of the ridges are irregular in profile and rise to altitudes of 1,400 or 1,500 feet. This area has the appearance of not having been reduced during the early Tertiary stage of erosion, and consequently now stands above the surrounding region.

From the above facts it is apparent that this peneplain is nearly flat in southwestern Pennsylvania and adjacent parts of Ohio, but a slight rise is observable toward the northeast, which as one ascends the Allegheny valley increases to such an extent that it carries the peneplain

to an altitude of about 1,300 feet in the southwestern corner of the Kittanning quadrangle in Butler county, 1,400 feet along a line extending from the northwest corner of the Kittanning to the southeast corner of the Rural Valley quadrangle, and to 1,500 feet along Redbank creek in the northeastern part of the latter area.

The northward rise is apparent also along the western face of Chestnut ridge in the group of quadrangles which previously has been mentioned as lying in the Monongahela valley and in the Latrobe and Indiana quadrangles adjacent on the northeast. About Indiana the peneplain was not extensively developed. The region is located away from the main drainage lines, and the conditions of erosion were not so favorable as they were in the Monongahela valley; moreover, the rocks appearing at the surface are more sandy, and they were not eroded to the same extent as in the other locality. Nevertheless the peneplain surface seems to be well marked on the present divide between the streams flowing into the Conemaugh river on the south and the minor tributaries of the Allegheny river on the west. This territory has been the scene of several cases of stream piracy.* The streams formerly flowing into Conemaugh river have been beheaded by Crooked creek, which is a tributary of the Allegheny river. The reason for this change is not apparent, but the fact that the change has been accomplished is without question. Since such changes usually occur on the rejuvenation of the streams after a period of extensive baseleveling, it seems altogether probable that the present divide, which was formerly an old channel of the captured stream, marks the general level of the peneplain. According to that criterion, its altitude is about 1,400 feet above sealevel.

North of this point there is little available evidence to show the extent and altitude of the Harrisburg peneplain. Judging, however, from its development in southwestern Pennsylvania and eastern Ohio, it seems probable that it is present in the Girard and Erie quadrangles, in the northwestern part of the State. The uplands in this region are composed of not very resistant rocks, and it seems highly probable that they were reduced during this cycle of erosion. The altitude of these tops is about 1,300 feet.

Thus it appears that the plateau surface developed on the Chemung rocks of northern Pennsylvania and southern New York resembles the Harisburg peneplain in that they are both peneplains of rather extensive development, involving most of the region except that occupied by the most resistant rocks; also the origin of both seemingly post-dates the Jura-Cretaceous cycle of reduction, and they are both manifestly older than the Somerville peneplain, which is developed only on the softest

*George B. Richardson: Geologic Atlas of the United States, Indiana folio, in press.

rock in the State. The observed slopes of the Harrisburg peneplain also seem to point to the correlation of this peneplain with the even hilltops of the Chemung areas of the northern part of the State, for it has been shown that in all localities, from the extreme eastern part of Pennsylvania to the shore of lake Erie in the vicinity of Cleveland, the Harrisburg peneplain rises toward the northern-central part of Pennsylvania and if the observed slopes of the surfaces were projected toward this central point, they would easily reach the Chemung upland of Tioga and Potter counties.

Thus the evidence obtained along several independent lines of research seems to point to the correlation of the Chemung upland of the northern part of the state with the Harrisburg peneplain of the eastern and western section, and consequently to its early Tertiary date of origin, and while these conclusions seem to be well supported, they are put forward now only tentatively in the hope that their publication may serve as a stimulus to further investigation.

DEFORMATION OF THE HARRISBURG PENEPLAIN

From the data herein given and from a close study of the topographic maps at present available, the writer has attempted to show by contour lines the deformation of the Harrisburg plain. The result of this study, although of a preliminary character, seems to indicate that the uplifts which have followed the formation of the Harrisburg peneplain have produced an ellipsoidal, dome-shaped structure with its area of maximum development in McKean and Potter counties, in northern Pennsylvania. The major axis of this structure trends about north 70 degrees east, extending far into Ohio on the west, and probably curving to the north in central New York and extending into the Adirondack region. On the south the evidence is not sufficient to determine the exact form of the uplift, but it seems probable that there is a secondary axis turning to the south and connecting with the main uplift of the southern Appalachian region.*

RÉSUMÉ

Briefly stated, the results of the present study are as follows:

1. The recognition in the plateau region of northern Pennsylvania and southern New York of the probable remnants of two peneplains.

2. The provisional determination by comparison with well known areas, of the early Tertiary date of origin of the lower surface, which is carved only on the softer rocks of the region.

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*See plate vi, Geomorphology of the southern Appalachians. National Geographic Magazine, vol. vi, pp. 63–126.

3. The recognition in eastern Pennsylvania of the Harrisburg peneplain of probably early Tertiary date of origin lying between the Schooley and Somerville peneplains as described by Davis.

4. The gradual northwestward ascent of this peneplain to an altitude of 1,200 to 1,300 feet along the Allegheny front.

5. The provisional correlation of this peneplain with a peneplain extensively developed in the southwestern part of Pennsylvania and in Ohio at an altitude of from 1,200 to 1,250 feet.

6. The determination of the north and northeastern rise of this surface.

7. The correlation of the Harrisburg peneplain as determined in the eastern and western parts of the state with the Chemung hilltops of Tioga and Potter counties, thereby corroborating the provisional determination of the early Tertiary age of the latter feature.

8. The determination of the ellipsoidal or dome-shaped deformation of the peneplain about a general center located in Potter or McKean county, where its surface reaches an altitude of about 2,200 feet above sealevel.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 14, PP. 297-304, PLS. 32-36 AUGUST 14, 1903

NORTHWARD FLOW OF ANCIENT BEAVER RIVER

BY RICHARD R. HICE

(Read before the Society January 1, 1903)

CONTENTS

Introduction

In 1890, in connection with Doctor Foshay, the writer discussed somewhat briefly the abandoned fluvial plains of Beaver river, and attention was called to the evidences of the direction of flow of the stream that eroded the fluvial plain that is now found high above the present stream level*. With the evidence that is furnished of the ancient slope by the fragments that are still to be found, attention is here specially directed to the evidence furnished by pot-holes found on the old river bed near Rock point.

History of Beaver River

The life history of Beaver river may be divided into a number of stages. One of the earlier stages is the time when it formed the line of northern discharge for the upper Ohio drainage, the fluvial plain above mentioned forming one of the later beds of the river at this stage of its history. This stage of the river's history was entirely pre-glacial. With the advance of the ice (the Kansan or pre-Kansan, as determined by Leverett †), this line of discharge was blocked and the waters of the

*Bull. Geol. Soc. Am., vol. 2, pp. 457-464.
† U. S. Geol. Sur. Mon. xli.

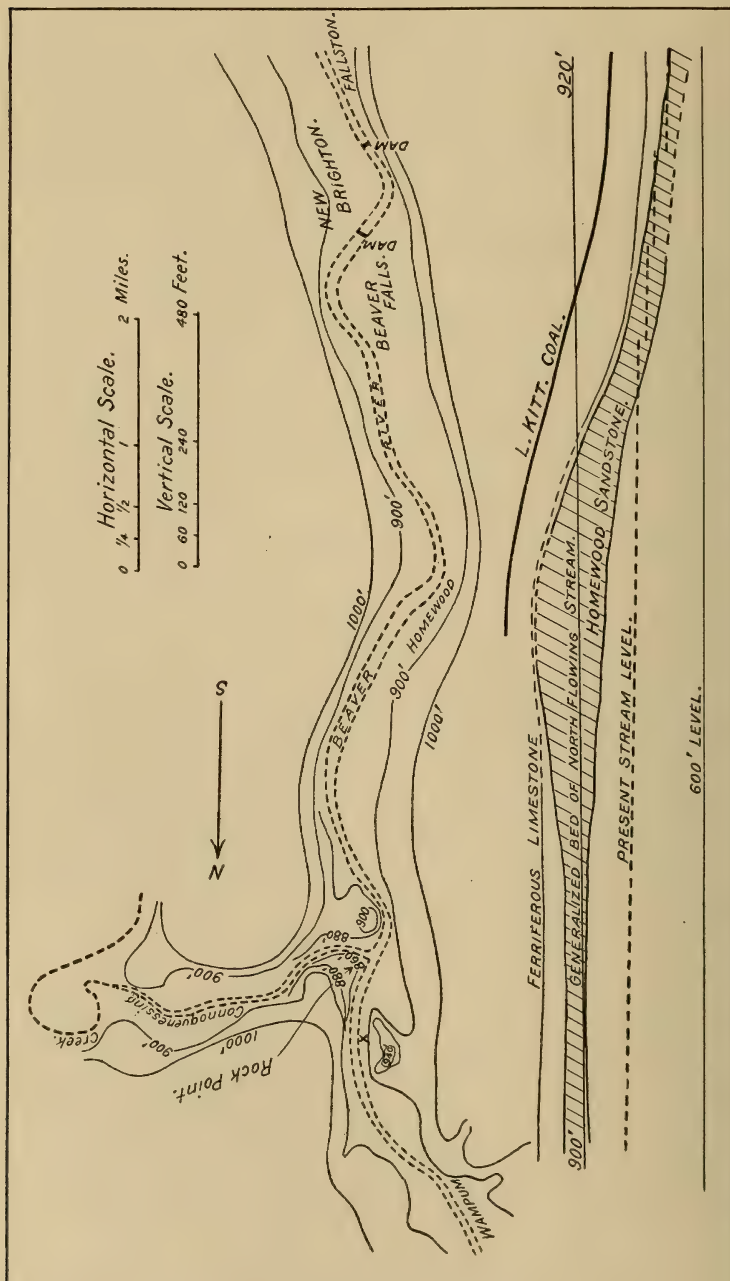


FIGURE 1.—*Map and Section of Portion of Beaver River*

Showing ancient river bed and relation of the Homewood sandstone to it. Contour lines are generalized in crossing side valleys

BED OF BEAVER RIVER

This general view is taken below Fallston dam, looking diagonally upstream

upper Ohio drainage, with large additions from the melting ice, were dammed, forming lake Monongahela, and the outlet was then either across some of the divides in West Virginia, as suggested by Doctor White,* or over the divide between the upper and middle Ohio drainage systems, at or near the line of the present stream. At different times it may have discharged in both directions. During the retreat of the ice following the Kansan stage, the line of discharge in the course of the present Ohio was established as we now find it, and it continued to cut until the streams of the upper Ohio region flowed below present stream level. This cutting is quite narrow, and on the lower 12 or 14 miles of the Beaver it is bounded by almost vertical walls, but north of Wampum this "inner" gorge is much wider and its walls are well rounded.

It is not yet determined whether the deep cutting of the "inner" gorge followed immediately on the retreat of the Kansan ice-sheet, or marks the work of a later portion of the time between the Kansan and Wisconsin invasions, as there are scattered evidences on some of the remnants of the bed of the north-flowing stream that seem to indicate the old level had not been abandoned, at least permanently, until after the time of the Iowan loess.

Following this stage of the river's history came the Wisconsin stage of glaciation, with its immense accumulations of alluvial materials along the drainage lines open to the southward, and this in turn was followed by the present stream, still eroding the Wisconsin gravels.

Figure 1 shows some of the features of the lower portion of Beaver valley, and the relations of the present stream and the old north-flowing stream to the various strata. The effect of the great thickness of the Homewood sandstone in restraining the cutting by the old river is plainly seen. To simplify the map, no contours are shown between the 900 and 1000 foot lines. The 900-foot line clearly indicates the almost absolute level of this portion of the old fluvial plain, and the 1000-foot line shows how uniform was the width of the old valley. The contours below 900 feet are only given at the mouth of the Connoquenessing to indicate the existence of two benches at that point. At other places the lower contours generally fall within the lines of the narrow "inner" gorge. The contours near Rock point higher than 900 feet indicate morainic deposits on the old fluvial plain. The top of the Homewood sandstone at its type locality (Homewood) is somewhat uncertain. Doctor White, from whose section I have taken the thickness at this point, says the top of the Homewood sandstone is concealed. It rises

* American Geologist, vol. xviii, pp. 368–379.

high enough, perhaps, to entirely cut out the ferriferous limestone. The measured thickness is 150 feet.

Lake Monongahela

Before taking up the phase of the north-flowing stage of the Beaver, which is the special subject of this paper, a few words regarding lake Monongahela are in place. Doctor White* has firmly established the existence of this lake, and all study of the subject since the publication of his paper has but confirmed his views. This is among the oldest of our glacial lakes, perhaps the oldest recognized one in the eastern portion of the United States. It was synchronous with one of the earlier stages of glaciation (Kansan or pre-Kansan), and therefore any beaches it may have formed and its channels of discharge have had very much longer time to lose their distinctive features than the other glacial lakes; so that while such records may be found, they have not yet been noted. We are therefore without any recognized beach lines by which we can judge of changes of elevation that may have occurred since the time of this lake. It is possible that a study of delta deposits may aid in such determination, but these will require very careful study on account of their great age as compared with similar deposits in other glacial lakes.

Abandoned fluvial Plains

The direction of flow of a stream is clearly shown by the slope of its bed, but in the case of abandoned fluvial plains we may not in all cases be certain of the direction, as the slope may have been distorted by differential elevation. Where there is no original horizontal line to be found, as apparently in the present case, it may not be entirely clear in which direction the old stream flowed. In the case of the Beaver there is not much difficulty of this kind. The slope of the fragments of the old river bed found on the lower Allegheny and the slope on the upper Ohio and Beaver (parallel streams), while quite small, are yet in opposite directions, and it is therefore evident that no great differential elevation has occurred, or, if so, it has practically disappeared. Any other supposition necessitates the assumption of a complicated and irregular uplift, entirely out of harmony with the uniformity existing in the region of the Great lakes.

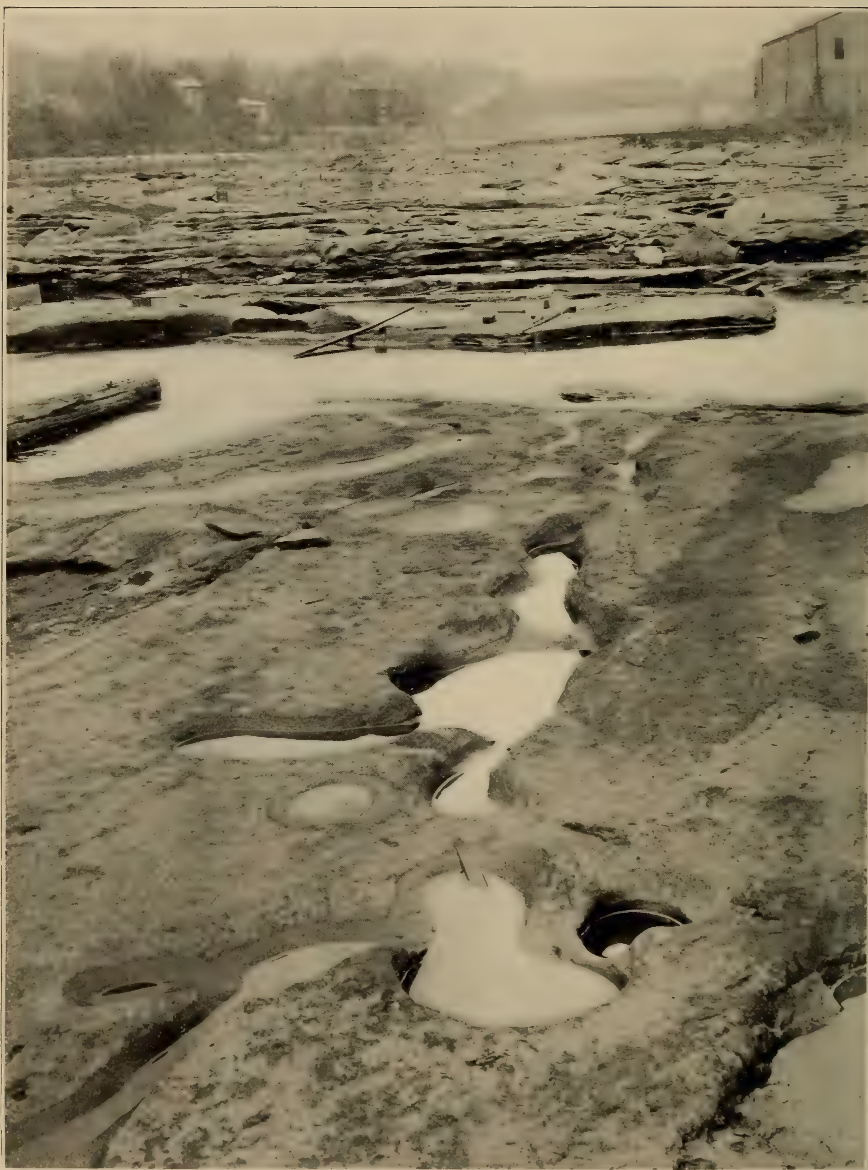
Pot-holes in present River Bed

The evidence of pot-holes as to direction of flow is, however, conclu-

*American Geologist, vol. xviii, pp. 368-379.

POT-HOLES BELOW FALLSTON DAM

View, taken looking upstream, shows eroded condition of downstream edge and abrupt upstream edge



POT-HOLES BELOW FALLSTON DAM

View taken looking downstream. Compare sides of pot-holes in the plate following

sive. As similar proof may be available at other places where the slope of the old bed is not definite, or may even be negative, it seems desirable to give more fully the facts showing the correctness of the opinion heretofore held in reference to them.

At and above Rock point, for about a mile, the old fluvial plain is in the Homewood sandstone, which here is a hard, massive stratum. It is well glaciated, being striated over quite an area. These markings, evidently due to the last advance of the ice in this region (the Wisconsin*) belong to a time much later than the erosion of the old fluvial plain, and show the great resisting powers of this stratum.

About 10 miles south of Rock point the same stratum now forms the bed rock of the present stream, which is marked by pot-holes from Beaver Falls dam to the edge of the stratum, where it is cut by the now buried channel of the Beaver, below the New Brighton-Fallston dam. The stream bed is especially eroded below the last-named dam, presenting such a number of pot-holes that many of them have been cut and enlarged until they have broken into adjoining ones. The locality is typical of this phase of stream erosion. It is especially advantageous to study the effects of erosion here in order that the "live" pot-holes may be compared with the "fossil" ones found in the same stratum near Rock point. It is also to be noted that the local character of the Homewood sandstone is almost absolutely identical with the same stratum at Rock point.

In the accompanying illustrations, plate 32 is a general view of the Beaver below the Fallston dam, looking diagonally up the stream. An examination of this will show the abundance of the phenomena to be found here, so much so that it is difficult at some places to get isolated examples for illustration. Attention is directed to the fact that the steep side of the pot-hole is in all cases the upstream side of the hole, while the downstream side has been rounded off and eroded by the impact of the water. Attention is also directed to the general slope of the bed of the stream, being almost 10 feet in the short distance shown in this figure. This is a somewhat greater fall than usual, due to the nearness of the buried channel, but a rapid flow of water is a requisite in the formation of pot-hole structure. Further reference to this will be made in applying the fact here noted to the locality at Rock point.

Plate 33 shows somewhat in detail three pot-holes which have not yet succeeded in entirely cutting away their dividing walls. This view, taken almost against the stream's flow, shows on the upper side of each pot-hole the steep, abrupt edge, indeed undercut, and on the downstream side that the rim has been rounded off and eroded. In each of the pot-holes the bottom is filled with water, as shown in the figure.

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* Leverett: U. S. Geol. Sur. Mon. xli.

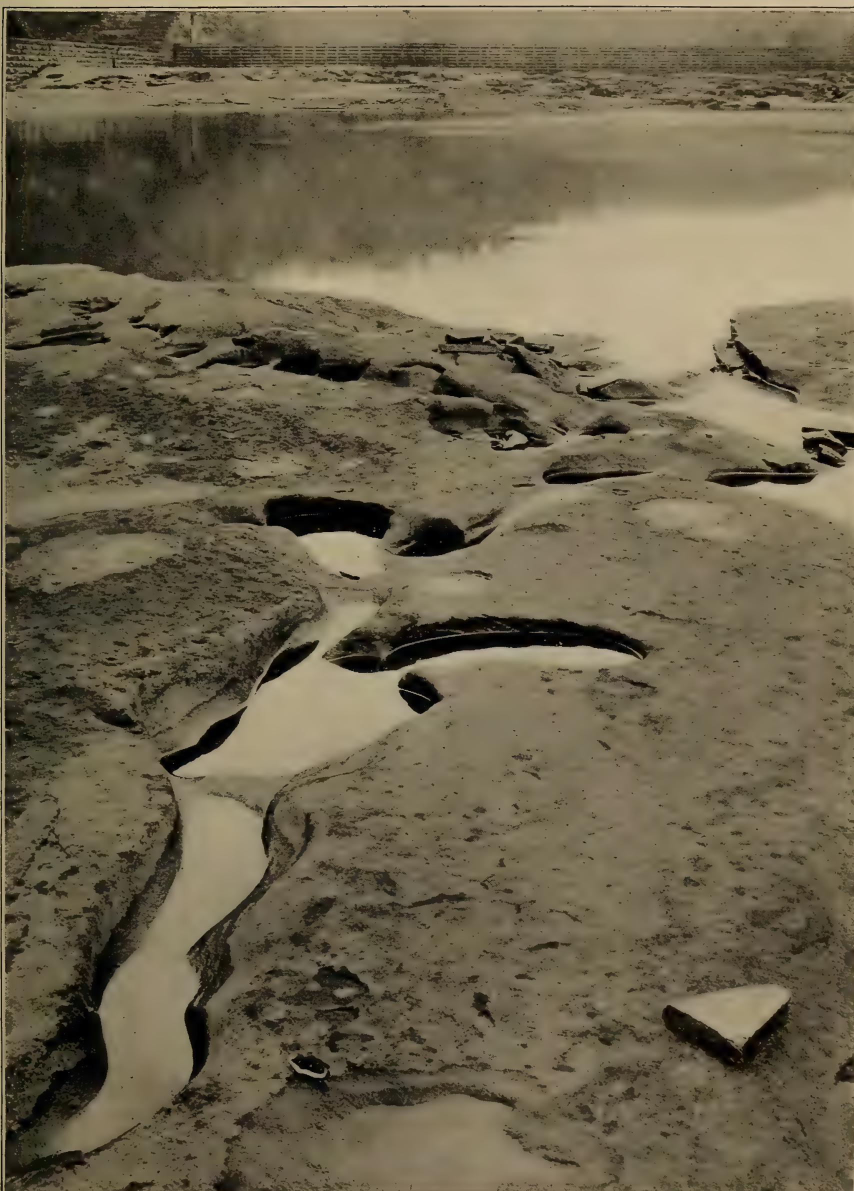
Plates 34 and 35 are two views of a more advanced stage of pot-hole erosion, in which the different holes have cut into one another, thus forming an irregular channel. Plate 35 is a view taken looking up the stream, while plate 34 is one looking down stream, both views being of the same group of holes and thus showing the difference in their appearance as viewed from opposite directions. The upper pot-hole of this series, seen near the bottom of plate 34, is quite typical. A small piece of drift which has lodged on the downstream edge is clearly seen, and its position shows the eroded condition of that edge of the hole, which is so beveled as not to produce any reflection from the water's surface, while the upstream edge is distinctly undercut (left center of plate 35). Looking up the stream (plate 35), the end of the piece of drift is seen on the lower edge of the pot-hole.

To the right of the line of the pot-holes is seen in plate 35 (on the left side in plate 34) an "arm" or branch, which was originally a pot-hole of irregular shape, now connected with the others. The difference between the two sides is clearly seen. In this case the downstream side is not so much eroded as in the others shown, due to the fact that the distance across, measured in the direction of the water's flow, is only about one-half the diameter of the pot-holes shown in plate 33, and hence the water does not yet strike with as great force in the one case as the other. A number of other pot-holes are seen in these plates, all telling the same story.

Similar examples might be shown almost without number, but these seem sufficient to indicate clearly the fact intended to be brought out thus far, which is, that in the formation of pot-holes it is the downstream edge that is eroded, while the upstream side is abrupt, and is often, indeed, undercut, as shown in plates 33 and 35. This being the case, it is the logical deduction that when we find such pot-holes their appearance will clearly indicate the direction of flow of the stream that formed them.

Pot-Holes in ancient River Bed

Plate 36, figures 1 and 2, are two views of a "fossil" pot-hole and surroundings found on the ancient river bed, near Rock point, at the point "X" in figure 1 (page 298). Figure 1 is a general view, and although the pot-hole has been somewhat damaged by blasting, it clearly shows the distinctive features of this phase of erosion. Figure 2 is a more detailed view. The shadow of the tapeline (the picture was taken at noon) defines the eroded side, and the steep upstream side is undercut. Both views are taken looking southward, or *down* the present stream, and the *northward* flow of the water that formed them is distinctly indicated.



POT-HOLES BELOW FALLSTON DAM

View taken looking upstream. Compare sides of pot-holes with previous plate

FIGURE 1.—GENERAL VIEW POT-HOLES NEAR ROCK POINT, LOOKING SOUTH

FIGURE 2.—DETAILED VIEW OF POT-HOLE SHOWN IN FIGURE 1

Shadow of tapeline shows eroded condition of northern edge; southern edge under cut

POT-HOLES NEAR ROCK POINT

Quite a number of these ancient pot-holes have been exposed as the overlying clays and gravels have been removed in the process of quarrying, and some have also been seen on the eastern side of the Beaver. All have their steep side on their *southern* edge, thus uniformly indicating a *north-flowing* stream.

Differences in reported Elevations

In the reported elevations of the old river bed there have been some differences, and while all students of the subject agree that there is a small fall to the northward from the mouth of the Beaver to Wampum, yet a confusion of figures is apparent. This confusion seems due to the fact that all have considered the rock bench along the Beaver as representing but one stage of the river, namely, the bed of the ancient stream at the time of its reversal. This is a mistake, as an examination will show that at least two stages are represented, one some 40 feet below the other. These two benches are well seen at Rock point. On the eastern side of the Beaver there is a bench about 100 feet above present stream level.* This level is easily accessible, being the much frequented Rock Point resort. The lower levels that have been reported here evidently belong to this bench. On the western side of the Beaver we find, however, the main bench, above the level of the New Castle and Beaver Valley railroad. The elevation of this road at Clinton, just south of the Beaver County line, is 900 feet above tide,† and here it lies on the bed rock, and at Thompsons, the next station north, the elevation is 860 feet above tide,‡ and here the track is below the level of the old river bed. The best determination of the level of the old river bed at the locality of the pot-holes is 900 feet above tide. The lower levels given by White § and Leverett || at Rochester, 865 feet, seem to correspond with the lower level at Rock point.

Erosion of "Inner" Valley by North-flowing Stream

North of Wampum, in the region of the wide "inner" gorge or valley above referred to, we do not find benches corresponding to the 900-foot level at Rock point, and it is suggested that the pot-holes point to the reason for this absence. The presence here of the massive Homewood sandstone restrained the eroding power of the north-flowing stream,

* White: American Geologist, vol. xviii, p. 377.
† Sec. Geol. Survey of Pennsylvania, vol. N, p. 214.
‡ Sec. Geol. Survey of Pennsylvania, vol. N, p. 214.
§ American Geologist, vol. xviii, p. 377.
|| U. S. Geol. Sur. Mon. xli, p. 152.

while the rising of the strata to the northward brought up the underlying, softer formations and exposed them to stream work. The pot-holes indicate a rapid current at this point, which could have been the case only by the cutting away of the underlying strata northward. This implies that part of the erosion of the wide "inner" valley north of Wampum, heretofore regarded as the work of the south-flowing stream alone, occurred before the time of reversal. The amount of such erosion we do not yet know. I have heretofore called attention to some rock benches near Moravia,* about 4 miles northward, at a much lower elevation, referring to them as remnants left in the cutting by the south-flowing stream. They may, however, in the light of the evidence of these pot-holes that the stream here fell rapidly, prove to belong to the system of the old north-flowing stream. They are higher above the stream than some remnants left by the south-flowing stream nearer the mouth of the Beaver, and if they prove to belong to the north-flowing stream, they will easily harmonize with the level of the old floor a few miles to the northward, which is 810 feet, as reported by Leverett.†

From Pittsburg to these pot-holes, a distance of almost 40 miles, the fall is practically nothing, but here there seems to be a sharp decline of some 80 feet in a few miles. There is no differential elevation to account for this great difference in the rate of fall, but these pot-holes seem to suggest that here there were at least rapids and perhaps a fall of some 80 feet in the old north-flowing stream at a time preceding the Kansan stage of glaciation.

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*Am. Jour. Sci., xlix, p. 116.
†U. S. Geol. Survey Mon. xli, p. 152.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 14, PP. 305-336, PLS. 37-46 SEPTEMBER 1, 1903

LEUCITE HILLS OF WYOMING

BY J. F. KEMP AND W. C. KNIGHT *

(Read before the Society December 31, 1902)

CONTENTS

* While this paper was in press Professor Knight died suddenly at Laramie July 28, 1903.

Historical Review

For a number of reasons special interest attaches to the geological features of the Leucite hills of Wyoming. The hills present a series of rock-types which, on the petrographical side, are unique and extremely important in the systematic study of the eruptive rocks. The rocks were the first with leucite discovered in America and, except for one occurrence in the Dutch Indies, the first to be observed outside the continent of Europe. The obvious joy of Professer Zirkel in recognizing them, as shown in his classic report on the rocks of the fortieth parallel, still arouses a responsive chord in the minds of the later, and above all the younger, workers who read his pages. They are the only eruptive rocks known to have original phlogopite, as Doctor Cross has remarked, and a rare hornblende in some of their flows still invites further investigation.

The petrographical characters, however, are not their sole claims to interest. They constitute a little group of volcanoes far removed from any neighbors of like kind and rise like landmarks amid the arid plateau of the Red desert of Wyoming. Their sheets, cones, necks, and dikes afford singularly interesting phenomena, to which no writer has thus far seriously addressed himself. Even the period of their outbreak has not as yet been demonstrated in print. No complete record of the number of exposures and no description and discussion of the individuals have hitherto appeared. It is to these structural and stratigraphic features that the present writers purpose to specially address themselves, but in the detailed study new exposures have been found involving some undoubted dikes, and some new petrographical notes have resulted. We also desire to make available a fairly detailed geological and petrographical guide, so that our successors may intelligently visit the hills and collect among them.

Previous Papers

The Leucite hills have been already mentioned five times in print. S. F. Emmons* rode up to the southern mesas and gathered the speci-

*S. F. Emmons: Geol. Survey of the Fortieth Parallel, vol. ii, p. 236.

mens subsequently studied and described by F. Zirkel.* Emmons describes the Hills as

" a number of little conical peaks protruded through the beds of the Laramie Cretaceous. . . . The form of some of these hills seems to indicate the outline of a former large crater, while to the north the lavas are spread out horizontally, capping the hills, and extend beyond the limits of our map, apparently forming the summit of North Pilot butte. Although no well defined Tertiary beds were found in actual contact with these eruptive rocks, it is evident from their position directly over upturned Cretaceous sandstones and adjoining Green River beds, where the underlying unconformable Vermilion Creek series is not seen, that they have been poured out, not only since the deposition of the latter Tertiaries, but since their partial removal by erosion."

On page 238, speaking of Pilot butte, Emmons states:

"It is evident that the soft Green River Tertiaries which once surrounded and covered it must have been eroded away in a similar manner to those around Fortification peak."

F. M. Endlich,† of the Hayden Survey, visited the more northern mesas, especially the one now called Steamboat, but named by him Essex mountain. It is mapped, however, far larger than it is. Endlich also visited what we call the Boars tusk, which he called Rock point, and which on the map of the Hayden Survey is called " Sentinel." Endlich refers to the rocks of some of the mesas as basalt and says they have olivine. Others he describes as grayish brown and showing only biotite. Zirkel's determinations and descriptions of the rocks from the southern mesas were available when Endlich wrote and are referred to by him. From a passing remark made in the paper of Doctor Cross, to be presently cited, it appears that Major J. W. Powell also visited the hills, but we find no published description from his pen. In December, 1896, one of us ‡ read before this Society a brief description, partly of their structural and partly of their petrographic characters. The paper was based on observations made both by the author and two assistants, but it left much yet to be done. It contained a small map, which was based on the state map issued by the United States Land Office. The map is very sketchy and defective, although somewhat less so than previous ones. Shortly thereafter Dr Whitman Cross § published a very careful description of the rocks, both from microscopic study and chemical analyses. Many important points were established regarding their systematic classifica-

*F. Zirkel: Geol. Survey of the Fortieth Parallel, vol. vi, p. 260.

† Eleventh Annual Report of the Survey of the Territories for 1877, pp. 5, 9, 10, 119, and 132; see also map 3 in the atlas of the xii annual report.

‡ J. F. Kemp: The Leucite hills of Wyoming. Bull. Geol. Soc. Am., vol. 8, p. 169.

§ Whitman Cross: Igneous rocks of the Leucite hills and Pilot butte, Wyoming. American Journal of Science, August, 1897, p. 115.

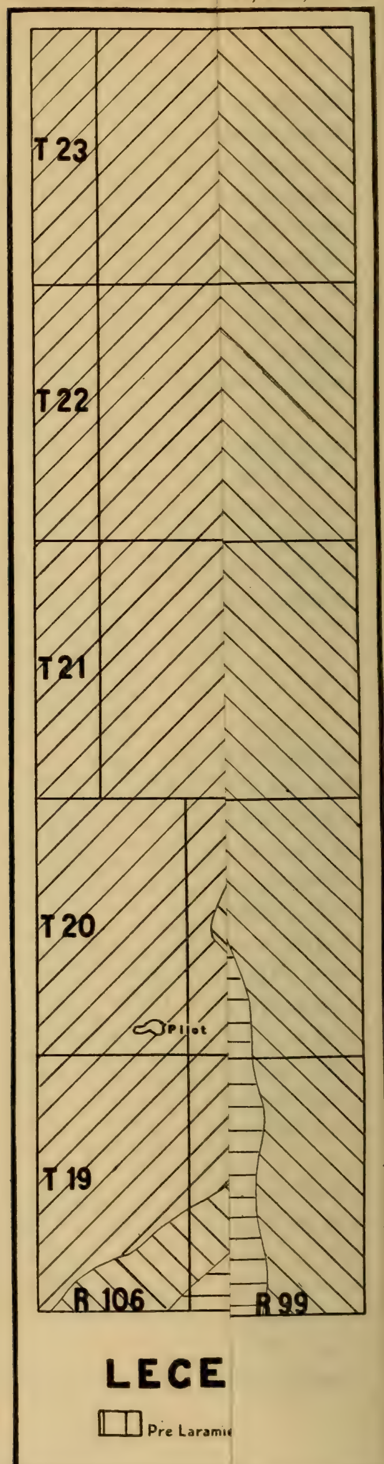
tion and incidentally concerning the general classification of all the leucite rocks. Doctor Cross gives but a brief outline of the structure and field occurrence. He appears to have regarded the separate mesas as having been once continuous and having been separated by erosion. Doctor Cross only visited the exposures, which we call Zirkel mesa, Orenda mesa, the Boars tusk, Pilot butte, and one that he mentions as North Table butte. This may be the one called by Emmons and by us North Pilot mesa. It is only fair to state further that his field and laboratory observations were made some years before those of J. F. Kemp, although unknown at the time to the latter, and delayed in publication because of other work.

Finally the present writers both felt the interest and desirability of more detailed study, description, and illustration. One of us (W. C. Knight) has made several trips alone, and both of us together spent some days camping among the mesas and buttes the past summer, studying, photographing, and collecting. We have discovered several exposures not previously observed and have endeavored not to overlook any important points connected with their structural relations.

Varieties of Rock

Professor Zirkel received specimens collected by Mr Emmons from the extreme eastern or southeastern end of the exposure which we call Zirkel mesa. In them he discovered only leucite, diopside, light brown biotite, and apatite. When, however, one of us (J. F. Kemp) came to examine a suite of specimens from widely separated points, varieties with abundant sanidine were observed and some that departed in the small amount of leucite from the type described by Professor Zirkel. Mr Emmons had also recorded trachyte from North Pilot butte, with no leucite. Doctor Cross named the original variety with abundant leucite "wyomingite;" the variety with little leucite, but with much sanidine and a rare hornblende, orendite; and the variety which consists of diopside, phlogopite, and apatite in an isotropic base, madupite. He explained the determination of trachyte by Mr Emmons as due to a now inexplicable confusion of slides.

Our observations show, however, that there are several different flows present in nearly all the mesas, and that the rock varies much in the same flow. From the same mesa and from the same flow two of the types, wyomingite and orendite, may be obtained, and as they can only be discriminated under the microscope they cannot be accurately collected in the field except from established ledges or flows. We have only found madupite at Pilot butte. Under the microscope it is obviously


T 23
T 22
T 21
T 20
Pilot
T 19
R 106
R 99
LEGE
Pre Laramie

more basic and basaltic than the others, and the analysis shows that it is 10 to 12 per cent lower in silica.

Geographical Situation and general Character of the Region

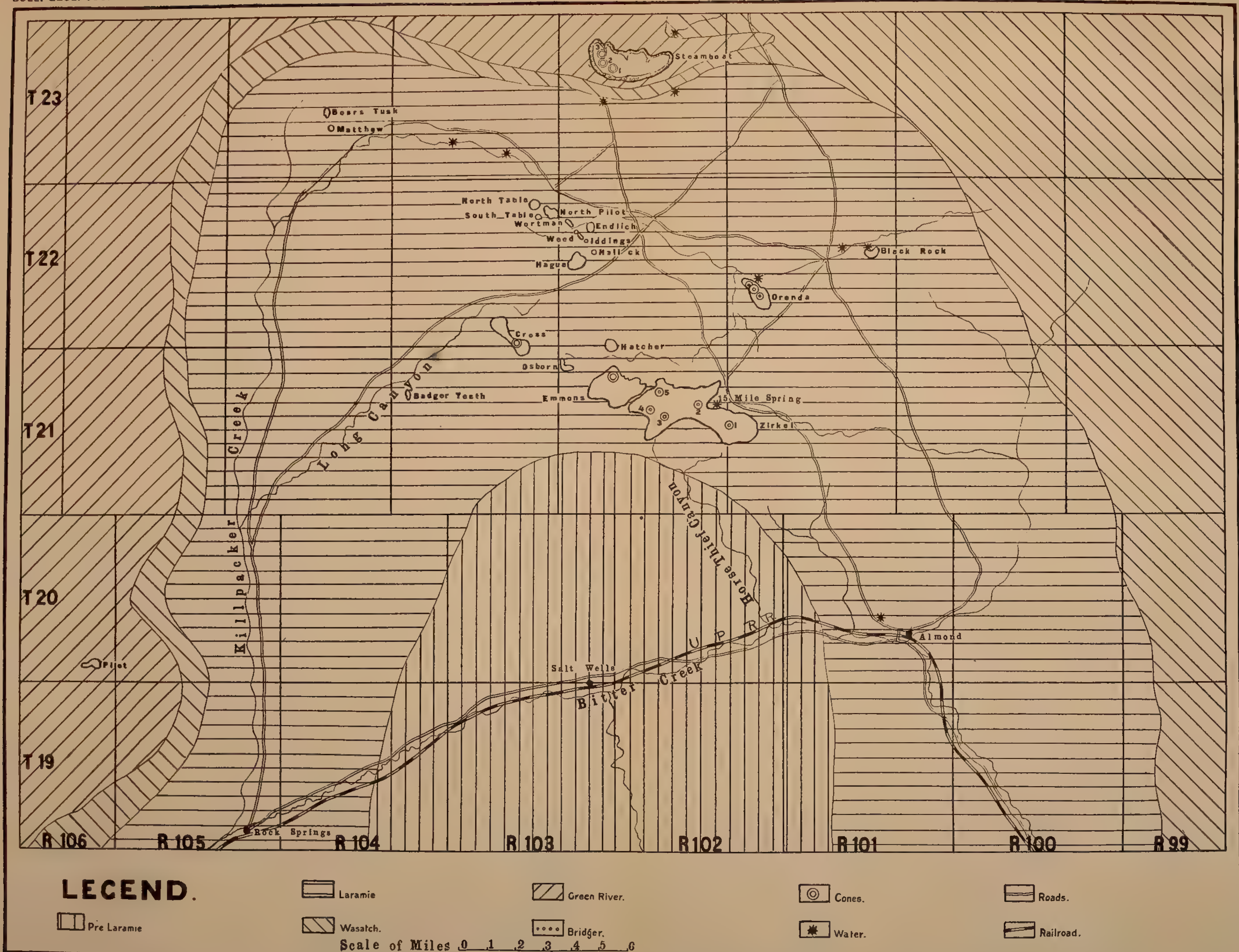
As shown on plate 37, the Leucite hills are situated in the southwestern portion of Wyoming between the exterior lines of ranges 101 and 105 and townships 20 to 23. They are a little north of the center of Sweetwater county. They extend over a distance of 30 miles from their eastern edge, Black Rock mesa, to their western representative, Pilot mesa, and about 25 miles from the most southern to the most northern exposures. The southern edge of the nearest exposure to the Union Pacific railroad is about 10 miles north of the Salt Wells siding, 15 miles northwest of Point of Rocks,* and, with the exception of Pilot, about 20 miles northeast of Rock Springs. From Point of Rocks and Rock Springs there are wagon trails leading to Atlantic and South Pass which pass the mesas, but Rock Springs is the best point at which to outfit for a visit to them. At the same time, the Leucite hills cannot be said to be easily accessible. The land is an arid desert except for a few springs. There are no ranches among them, although a few horses and cattle range them in summer, and in winter, when the snow furnishes drinking water, sheep herders use both the mesas and the intervening valleys as ranges. Despite the apparent aridity, there is much nutritious bunch grass and excellent pasturage. Along the talus slopes cotton-tail rabbits are abundant and sage hens frequent the neighborhood of the water-holes. Yet an ordinary trip by daylight gives no conception of the teeming life of the desert. One of our drives took us late one afternoon across the sand dunes which lie south of Steamboat mesa and which are 2 or 3 miles wide. A gale of wind was driving the sand before it and smoothing out all marks upon the surface. Toward night the wind subsided, and in the morning at 7 o'clock, when we again crossed the drifting sand, there was hardly a square foot that did not exhibit a track of insect, quadruped, or bird, although to all appearances the dunes were almost devoid of life.

It is a question whether Pilot butte (or mesa) is to be classed with the Leucite hills. Doctor Cross makes a distinction. It is, however, embraced in this general name by us.

General Geology

In the midst of the Red desert there is a huge dome of Cretaceous

*Point of Rocks is the name of the station, on the Union Pacific railroad, and is a small frontier settlement of long standing. The post-office is, however, Almond, which name appears on our map.



GEOLOGICAL MAP OF THE LEUCITE HILLS, SWEETWATER COUNTY, WYOMING

By W. C. Knight and J. F. Kemp

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strata that is approximately 40 miles long and 30 miles wide. Bitter creek in its westward course crosses the greater axis nearly at right angles and has carved a broad valley which cuts this elevated area into two nearly equal parts. Along this valley the Union Pacific railroad has constructed its line. This dome has been greatly reduced by erosion, for from its crest there has been removed not less than 5,000 feet of Laramie, and practically an equal thickness of Cretaceous rocks below the Laramie. The pre-Laramie formations have not been satisfactorily determined, and occupy a tongue-like mass 12 or 14 miles in width along the Union Pacific railroad and extend from Salt Wells a distance of about 8 miles to the northward. The Laramie formation north of the Union Pacific railroad occupies a semicircular area and is made up of a series of concentric hogbacks. On the western side of the dome this formation has a width of 6 or 7 miles, and Rock Springs is nearly in the center from east to west. From this point it extends to the northward and gradually widens, and where it swings to the eastward it is not less than 14 miles from north to south, the northern limit being at the base of steamboat mesa. It extends considerably farther to the eastward, but eventually swings to the southward and crosses the Union Pacific railroad at Black buttes, where the formation is about 8 miles in width. About the exterior border of the Laramie there is a slight development of Wasatch Tertiary. This is well exposed 3 miles west of Rock Springs and 4 miles east of Black buttes. To the northward these beds have been covered with sand and soil and are only occasionally seen. Above the Wasatch there are extensive developments of Green River shales, which along the western flank of the dome rise in precipitous bluffs, varying from 400 to 900 feet high. The Green River formation has been traced several miles east of Steamboat; but southward from the bluffs east of Steamboat it has been removed by erosion and is not seen again until one approaches the railroad. To the northward of the Leucite hills there are isolated areas of Bridger resting on the shales.

Owing to the fact that the Green River shales along the western flank of this dome dip to the westward at an angle of from 4 to 6 degrees, it is evident that the elevation of the dome must have been post-Green River and possibly later. Since its uplift, sufficient time has elapsed to remove all of the Tertiary rocks from the greater portion of the uplift, and to have cut deeply into the Cretaceous below.

Resting on the northern half of this dome or on the Tertiary rocks covering it are the Leucite hills, all of which, with the exception of Pilot mesa, are supported by the Laramie or are very near the edge of its eroded surface.

The elevation of the region varies from 6,300 to nearly 8,000 feet.

There are no important creeks or rivers that flow through or rise within it. Bitter creek, the largest waterway, passes to the southward of the Leucite hills, but receives the drainage from Killpacker creek, which rises near Boars tusk, and also from a few gulches along the southern side of the Leucite hills and from the gulch heading at Fifteen-mile spring. All of the remainder of the drainage from the Leucite area is to the eastward and is tributary to the Great Divide basin.

The separate or detached exposures of the leucitic or their closely related rocks are now known to be twenty-two. They range from talus-covered hills, isolated volcanic necks, and associated dikes, as in the Boars tusk and Badgers teeth, to lava flows with cones, as in the case of most of the exposures. Besides these we apparently have in the "Tables" examples of intruded sheets at different horizons, and one dike has been met at a distance from a volcanic neck.

The mesas have in some cases been built up of demonstrably successive flows, and on top of these are the cones. The cones are generally formed of fragmental pumice or of very cellular scoria, but at least one is a huge blister of solid lava. Observation of the last named led one of us (J. F. Kemp) to infer that the cones generally were blisters,* but subsequent study of the other cones proves that they are almost all composed of fragmental rocks and are segments of older cinder cones, whose major part has been removed by erosion.

The Twenty-two Leucite Hills

The twenty-two separate exposures are shown on the accompanying map, from which their relations may be seen at a glance. This map is based on the one of the U. S. Land Office, but the locations have been checked, by observations with a Brunton pocket transit, from cone to cone or from one recognizable feature to another. The need of names in order that we may distinguish the separate exposures in the descriptions has led us to apply to those which, so far as we can learn, have hitherto received none the names of geologists who have been concerned in their study or have contributed in other important ways to the geology of Wyoming.

In our nomenclature we have sought to apply the name "mesa" where the exposure is flat and like a table, even though it might have a cone on it and thus suggest a butte, and even though it had been called a butte before, as in the case of Orenda, Pilot, North Pilot, Steamboat, and Black Rock, which are currently called buttes. Butte, of course, implies a sharp or pointed elevation, and is not to be correctly used for these

*Bull. Geol. Soc. Am., vol. 8, p. 174.

dissected and remnantal lava flows with their flat tops and precipitous escarpments.

We take up the exposures in a general order from the southeast corner, west and north across them. This order happens also to bring together individuals of related character.

Mesas without cones

Black rock	Described by Kemp.
Hatcher	Not previously noted.
North Pilot mesa	Described by Cross (?)
North table	Not previously described.
South table	Not previously described.
Pilot	Described by Emmons, Kemp, and Cross.
Osborn	Not previously noted.

Mesas with cones

Zirkel	Described by Emmons, Kemp, and Cross.
Emmons	Not previously noted.
Orenda	Described by Kemp and Cross.
Steamboat	Noted by Endlich but not described.
Cross	Not previously noted.

Volcanic necks

Badgers teeth	Not previously noted.
Matthew hill	Not previously noted.
Iddings butte	Not previously described.
Boars tusk	Described by Cross.
Weed butte	Not previously noted.
Hallock butte	Not previously noted.

Dikes

Wortman dike	Not previously noted.
Iddings dike	Not previously noted.

Talus covered hills

Endlich hill	Not previously noted.
Hague hill	Not previously noted.

Zirkel Mesa

GEOLOGY

This is much the largest of the exposures. It consists of lava flows, with a high and nearly vertical but indented escarpment on the southern side and a deeply dissected one along the northern face. It is a dissected series of lava flows which rest directly on the Laramie, whose beds, richly provided with *Ostrea glabra* (Meek), outcrop one-eighth of a mile south

of Fifteen-mile spring. The Laramie beds dip about 5 degrees northwest and strike northeast. The mesa has an abrupt escarpment which, while more or less precipitous, is broken by small gulches which give access to the top. In a few places it may be scaled by horses. The escarpment is surrounded, as are indeed those of all the mesas, by a heavy talus, which masks the lower contact. The edge at the northeast corner is illustrated by figure 3 of plate 14, volume 8, page 174, of the Bulletin.

The mesa's long axis runs east and west a distance of about 5 miles and its general width is 2 miles and less. It is impossible to state any accurate dimensions because of the dissected condition, in consequence of which long promontories run out from the main border and leave intervening gulches. A very large promontory extends northeast and southwest to the west of the re-entrant angle in which is Fifteen-mile spring.

The mesa is built up of a complex of at least two and probably three distinguishable flows and there may be a number of others. These are recognizable because they appear one over the other, and in a few places show evident contacts. At the head of the Fifteen-mile Spring gulch we believe that we can distinguish a lower flow of light colored pumiceous lava, on top of which rests a later one of dark, vesicular lava. The contact is not specially sharp, but appears to be masked by a bed of badly weathered volcanic breccia. The under flow extends far to the northeast beyond the escarpment of the upper one, and forms the northwest enclosing wall of the Fifteen-mile Spring gulch. The two flows seem to have followed one another at comparatively brief intervals, since the observable, secular weathering of the undermost sheet is slight. Still, too much importance must not be attached to this matter, because the leucite rock resists weathering notably well. The separate flows also appear in distinct terraces and by this feature indicate their relationships. Single sheets certainly extend several miles and of thickness not greater than from 30 to 50 feet. Some portion of the top has no doubt been removed in the long course of geological time, and has thus caused the sheet to appear today with less than its original thickness. The upper surface is usually fairly smooth and resembles a huge tessellated pavement, because of the joints; again it is rough and ridge-like, because of cross-depressions. Small faults are quite probably the cause of some of the irregularities. The sheets were doubtless nearly horizontal when they were originally poured out, but they show evidence of tilting to one who sights with a hand level. From the summit of cone number 2 it is evident that the lava flow slopes upward to the south, so that its southern rim is as high as the cone itself. This would involve a rise of about

250 to 300 feet in a distance approximately 2 miles. Again southwest of number 5 the sheets rise to the height of number 5 within three-fourths of a mile. Number 5 is 225 feet by aneroid above the mesa at its base. The rim at this point is not so high, however, as cone number 4.

CONES

There are five cones arising from the surface of the mesa. We have numbered these, beginning with the eastern one, numbers 1 to 5. The statement in volume 8, page 175, of the Bulletin that there are six is due to the supposition that Zirkel and Emmons mesas were connected.

Cone number 1 is not a complete cone, but a half circle opening to the west. It is 210 feet high and consists of fragments of pumice. An illustration of it viewed from the east from a distance of a mile or more appears in figure 2, plate 14, of volume 8 of the Bulletin. Soon after the elevation was determined the barometer gave the reading 7,250 feet at Fifteen-mile spring. At the base of the flow it read 7,525 feet, at the base of number 1 cone 7,640 feet, and the crest of the cone 7,850 feet.

Cone number 2 is more conical and less evidently a remnant of a ring. It is chiefly, if not entirely, made up of fragments of pumice. It rises about 250 feet above the mesa. The slope of its surface is 17 to 18 degrees.

Numbers 3 and 4 lie southwest of number 2 and a mile or more distant. Number 5 is a mass of solid lava.

We take pleasure in naming this mesa after Professor Ferdinand Zirkel, of the University of Leipzig, who was the first to recognize the leucite in these rocks and to whom American petrographers in particular owe so great a debt for his petrographic report on the rocks collected by the geological survey along the fortieth parallel.

PETROGRAPHY

Twelve thin-sections have been prepared of the rock of Zirkel mesa, distributed so generally over its area that there is little chance of new varieties appearing. Eleven of the twelve proved to be orendite, the remaining one being wyomingite. Our wyomingite was obtained at the extreme western end, and is the rock described as the rich leucite rock by one of us and figured in the earlier paper.* A photomicrograph is reproduced as figure 1 of plate 38. This rock also contains the yellowish hornblende described by Doctor Cross, although in his original wyomingite this particular constituent did not happen to occur. It was overlooked by one of us (J. F. K.) in preparing the previous paper, its

* Bull. Geol. Soc. Am., vol. 8, p. 177, fig. 2.

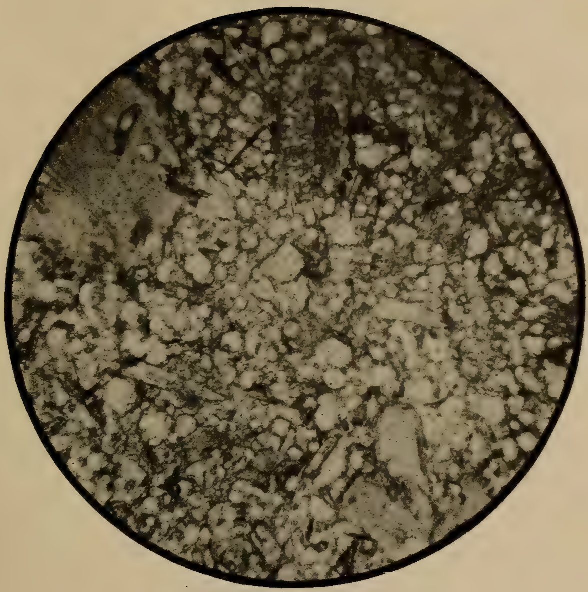

FIGURE 1.—WYOMINGITE OF ZIRKEL MESA

The round white minerals are lencite; the rods are diopside; the large dark ones are phlogophite. Actual field, 1 millimeter.

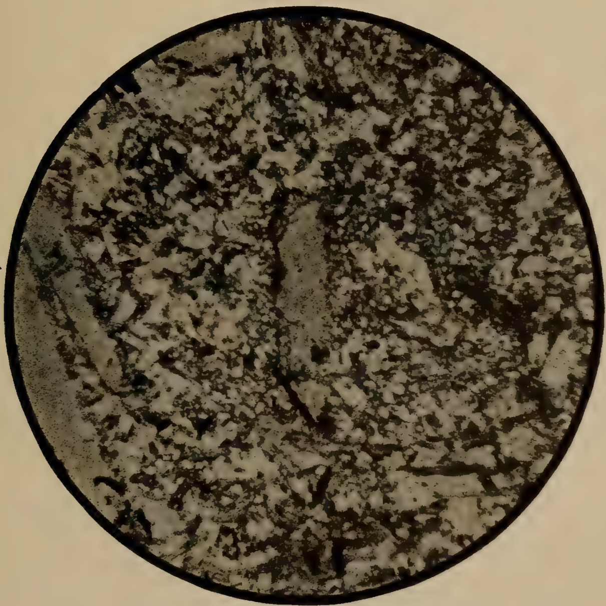

FIGURE 2.—ORENDITE FROM FIFTEEN-MILE SPRING, ZIRKEL MESA

Round white minerals are leucite; the white rods sanidine; the small dark rods diopside; the large dark mineral phlogophite. Actual field, 1 millimeter

PHOTOMICROGRAPHS OF WYOMINGITE AND ORENDITE

representatives being considered, as they have but inconspicuous development, to be small phlogopite crystals in the groundmass. In other respects it does not vary essentially from the typical wyomingite of Cross. Doctor Cross gathered wyomingite near the Fifteen-mile spring, but although we have prepared several slides from material collected there by us, they all proved to be orendite. There is little doubt that wyomingite is merely a local development in a flow which is elsewhere chiefly orendite. Chemically, as shown by Cross, the rocks are practically identical, since of analyses IV and V given in his paper, IV being wyomingite and V orendite, no two percentages of the same oxide differ more than two or three tenths of one per cent, except the alumina. This in wyomingite is about one and a half per cent more than in orendite. The others hardly differ beyond the ordinary variations of duplicate analyses. If, however, in one rock we have a large percentage of sanidine with 64 per cent of SiO_2 and in another leucite with only 55, of necessity the excess left by the latter must be present in some more acid silicate or in a highly silicious glass. Doctor Cross's observations with the microscope led him to believe that the latter existed in the slides.

Even in the orendite one often remarks the tendency of the leucite to gather in swarms in certain parts of the slides, and to thus afford patches of wyomingite in the midst of a general orendite, and the rock wyomingite is only a development of this character in a mass at least large enough to afford a hand specimen, and it may be indefinitely larger. We can detect no mineralogical difference between different flows. Should future visitors to the Hills desire to collect wyomingite, it will be safer to do so from the dikes as subsequently described or from the South Table.

The orendite of Zirkel mesa corresponds in all essentials to the descriptions of Doctor Cross. It is illustrated by the photomicrograph on plate 38, figure 2. It consists of leucite, sanidine, diopside, variable amounts of hornblende, phlogopite, apatite, and what is doubtless rutile. The relative amounts of each of these vary considerably. The hornblende may fail, but in careful search it is almost always to be found at least in small amounts. In the latter case it is, in its usual section, so near the color of the phlogopite that, as in the earlier observations of one of us, it may escape notice. The ray, vibrating parallel with *b*, is often of a violet hue, suggesting the characteristic colors of the titaniferous pyroxenes. Doctor Cross mentions rutile with a query. There is little doubt that this mineral is present and sometimes in considerable quantity. It is a deep reddish brown, and is sometimes prismatic and again in small irregular masses. In some of the other mesas it has been found in characteristic sagenite nets in the phlogopite.

In color the rocks vary all the way from a rich cream color, through light to dark reddish brown, to dark gray. In texture they range from the light porous pumice of the cones, through very vesicular amygdaloids, to dense platy varieties resembling typical phonolites. On fractured surfaces the amygdaloids have a waxy appearance, very like some phonolites. Nearly all of our hand specimens contain inclusions of the rock, through which the lava has reached the surface.

Emmons Mesa

This was probably once the western end of Zirkel mesa. It is a rough parallelogram in shape with a red cone at its northwestern corner (see plate 39, figure 1). The cone is a prominent landmark and from its peculiar color may be easily distinguished from all points of view. In other respects Emmons mesa appears to be much the same as the neighboring Zirkel mesa, from which it has been separated by the erosion of the intervening gulch. There seems to be entire correspondence along the sundered escarpments, and it is probable that some subterranean watercourse led to the collapse and removal of the lava which has disappeared.

We take pleasure in naming this mesa after Mr Samuel Franklin Emmons, of the U. S. Geological Survey, who first collected the rock of the Leucite hills.

One specimen has been gathered by us from Emmons mesa, which proves under the microscope to be a typical wyomingite, but we can not say that the entire mesa is of this character.

Osborn Mesa

This is a lofty and commanding mesa not of great superficial area. The mesa is shaped somewhat like a short-footed stocking or sock, with its long dimension running north 40 degrees west, magnetic. At the base on the north side the aneroid recorded 7,760 feet and the angle of slope was 15 degrees up to the escarpment, which then arose nearly vertically. The top was estimated at 400 feet above the gulch. Our specimens were gathered from the talus, on the northwest side.

Under the microscope the rock from Osborn mesa proves to be a typical orendite. Leucite is present in moderate amount, sanidine is abundant, while diopside, a little hornblende, and phlogopite make up the other principal constituents. Deep, mahogany-colored rutile is conspicuous in our slide.

We take pleasure in naming this mesa after Professor Henry Fairfield

Figure 1.—Emmons Mesa and Red Cone from the North

Figure 2.—Hatcher Mesa from the South

EMMONS MESA, RED CONE, AND HATCHER MESA

Osborn, of the American Museum of Natural History, in recognition of his researches among the fossil beds of Wyoming.

Cross Mesa

This is the most western one of the principal flows, but the Badgers teeth, the Boars tusk, and Pilot butte lie still farther in this direction. Cross mesa is a lofty and commanding fragment in the shape of a dumbbell about 2 miles from northwest to southeast and a half mile wide at either end and less in the middle. From the valley to the northwest it rises 400 feet over a rather steep slope of Laramie, which is covered with a scattered talus of lava. The precipitous escarpment about 40 feet in height then ascends abruptly, but is broken by re-entrant gulches up which one may climb. Great joints have separated blocks from the main mass, and these, after splitting away 10 feet or so, remain standing so that clefts and dens are afforded behind them, which are utilized by various rodents.

From its extreme western point the mesa runs eastward for about a mile and a half to a point where an apparent cone some 200 feet high arises. When observed closely it is found not to be a true cone, but the semicircular half of an old ring, with its concavity to the south. There is reason to think that the ring was once complete, but that the southern half has been entirely removed by erosion. The convexity of the curve is its high point; from this it slopes down to the horns of the lunette, which are 200 yards apart. It is built up of fragments of pumice. The angle of the outside slope was 23 degrees and of the inside 11. The rock of the flow is a cellular lava, but it has granitoid inclusions of coarse feldspathic rock. There was evidence of only one flow, so far as noted by us, the top being very flat and regular. Only one flow appeared in the escarpment.

The chief rock of this mesa is orendite, with leucite, sanidine, diopside, hornblende, phlogopite, and rutile. Near the cone and at its west foot we also gathered wyomingite, or at least orendite very poor in sanidine. Along the southern escarpment we found an included boulder of some coarsely crystalline feldspathic rock, now greatly altered. Under the microscope it exhibits untwinned feldspar, greatly strained and filled with small inclusions apparently produced by the influence of the lava, as in contact metamorphism. The boulder probably came from the ancient crystallines, on which the sedimentary rocks of this region rest.

We name this, which is one of the most striking of the group, after Dr Whitman Cross, of the United States Geological Survey, to whose

studies we so largely owe our knowledge of the detailed petrography of these lavas.

Hatcher Mesa

This is located about a mile north of the Red cone on Emmons mesa and is a conspicuous mesa with a high vertical scarp and a nearly flat top, which is about a half mile in diameter. It is illustrated by figure 2 of plate 39. Its elevation above the sea was not taken, but it will not exceed 7,600 feet. In this instance the talus from the capping lava has reached the valley which passes the southern base, having traveled a vertical distance of about 500 feet. While the rock looks very much like that from the other mesas, it is, as a rule, more vesicular and also contains many more inclusions and in greater variety than any other noted. Chief among these inclusions were rounded fragments of granite or of some ancient crystalline rock.

This mesa has been named after Mr J. B. Hatcher, of the Carnegie Museum, Pittsburg, in recognition of his valuable services in connection with Wyoming paleontology.

Under the microscope the rock of this mesa presents characters not elsewhere seen. It is partly aegirite-wyomingite and partly aegirite-orendite. The principal minerals of the former are leucite, diopside, aegirite, hornblende, and phlogopite, while the latter has in addition sanidine. The aegirite occurs in acicular crystals, of the usual green color, of rather feeble pleochroism and nearly or quite parallel extinction. It also forms the ends of diopside crystals, as it is so prone to do in other rocks. Its characters are the same in both the wyomingite and the orendite. The latter exhibits beautiful sagenite nets in the phlogopite.

North Pilot Mesa

This is the most conspicuous of all of the leucitic exposures, and has been well named, for upon entering this region from any direction it is truly a pilot, as it rears its truncated cap upwards of 1,000 feet above the eastern base. From a distance the mesa appears to be nearly round, but upon examination it proved to be elliptical, with the longer axis extending northwest and southeast and being nearly a half mile in length. The elevation, as determined with an aneroid barometer, is 7,750 feet. It is nearly surrounded with a vertical scarp, which varies from 25 to 50 feet in height and is inaccessible, with the exception of the northeastern face, where the large talus blocks reach nearly to the top of the mesa. From the surrounding country the surface appears to be nearly level, but it is quite uneven, owing to the relative facility

FIGURE 1.—GROUP OF THE LEUCITE HILLS

View from south, six miles distant. Mesa on far left is sedimentary, next to it on the right is North Table, South Table faintly showing in front. Lofty mesa next to right is North Pilot. In the background to right is Steamboat, followed by Endlich in the foreground.

FIGURE 2.—NORTH PILOT MESA

From southeast at a distance of three miles

FIGURE 3.—NORTH PILOT MESA

From the north, with talus in foreground

GROUP AND MEMBERS OF THE LEUCITE HILLS

Figure 1.—Cleft near Escarpment of North Pilot Mesa

Probably caused by a spring

Figure 2.—North Table and South Table

As viewed from North Pilot mesa; North Table in center and South Table on extreme left

CLEFT NEAR ESCARPMENT AND NORTH AND SOUTH TABLE

with which the softer portions of the leucite rocks weather. About the scarp there are numerous fissures, varying from a few inches to several feet in width, which have been made by the gradual giving away of the soft rock on which the flow rests. One can easily trace them in all stages of development from a tiny crack to an opening several feet across, and finally to the stage in which the block has toppled over to join the vast accumulation of large and exceedingly angular fragments below (see plate 40, figure 3, and plate 41, figure 1). The talus has accumulated in almost impassable masses about the greater portion of the scarp, and extends down the slopes of the mesa for a distance of over 700 vertical feet. The lower portion of the lava in this mesa has a reddish color and is quite porous. Usually it breaks with a conchoidal fracture. Along the western face of the scarp there are great zonal developments, in which there are well defined concentric rings that have a diameter of 20 feet or more. The mesa rests on Tertiary rocks, but on account of the obscuring talus it is impossible to say exactly on what formation. From the elevation of the eruptive mass they appear to be the Green River shales. At a point three or four hundred feet below the crest there are typical Laramie rocks exposed along the eastern slope and two workable seams of coal, which dip only a few degrees to the northward. Doctor Cross seems to refer to this mesa in his paper as "North Table butte,"* while Endlich states that it is marked on some maps as "Black butte."† We think that from the crevice figured on plate 41, figure 1, Doctor Cross obtained his potash niter.

In some respects the rocks of this mesa are, petrographically, among the most interesting of the hills. Specimens gathered along the north side and at the base of the escarpment are very near madupite—that is, they are without sanidine and with moderate powers show phlogopite, diopside, and apatite in a base which is so fine and dense that it is difficult to make it thin enough for study. With very high powers, however, it reveals minute diopsides and swarms of little leucites about .002 millimeter in diameter. Some glass appears between them, but with such small leucites it is very difficult to make a distinction as between them and the glass. The rock was doubtless developed by the relatively quick chill at the base of the flow. At the east end on the crest wyomingite was collected with some hornblende. Along the north side from the talus blocks typical orendite was secured, the pink varieties of which are very rich in the peculiar yellow hornblende. The latter in one of our specimens practically replaces the diopside entirely. In the sections, too, olivine will be found forming the center of phlogopite

*Amer. Jour. Sci., Aug., 1897, pp. 116, 117.
†Hayden Survey, 1876, p. 133.

crystals or else surrounded by a rim of phlogopite, a not unnatural relation for two orthosilicates of the same normal, principal base, magnesia. The phlogopite is often surrounded by crowns and borders of rutile, which make a deep mahogany colored rim. Leucite is extremely rare in some of these rocks, while sanidine is correspondingly abundant. Of themselves the rocks make very good trachytes in their mineralogy, being variations from the typical trachytes, chiefly because of the abnormal abundance of diopside.

North Table

Northwest of North Pilot and less than a mile away there is a mesa with a surface as level as if it had been planed, but it is 235 feet below the crest of North Pilot (see plate 41, figure 2). About it there is a quite prominent scarp. There are also highly inclined talus slopes, such as accompany all of the mesas. The top is between a quarter and a half mile in diameter. The eruptive rock closely resembles that from other localities, but the thickness of the sheet appears to be less than is usual. We call this the "North Table" in distinction from "South Table," whose description follows:

Four slides have been prepared of the North Table, all from the northeastern portion. Three are orendite and one is wyomingite. The peculiar yellow hornblende is very abundant and with its increase diopside wanes. The wyomingite is a pinkish rock, while the orendites are grayish brown. All are more or less vesicular.

South Table

This is the smallest mesa in the Leucite hills, being much less than a quarter of a mile in diameter and 400 feet below North Pilot in elevation (see plate 41, figure 2). There is a quite prominent scarp about it, and the rocks, so far as examined, are largely schistose, the schistosity being developed vertically. The rock is dense and platy, and appears to be an intruded sheet, both in its structural relations and in its petrographical characters. The vertical schistosity would suggest a vertical movement, but this is hard to understand in a mesa. It is possible that the pressure on the rock which was required to force it between strata caused the phlogopites to arrange themselves across the line of thrust.

Two specimens were gathered from the mesa, and both are typical wyomingites. Leucites make up much the greater part of the rock, and exhibit all the characteristic features of this mineral. They are of good size and are excellent for study. Diopside and phlogopite are practically

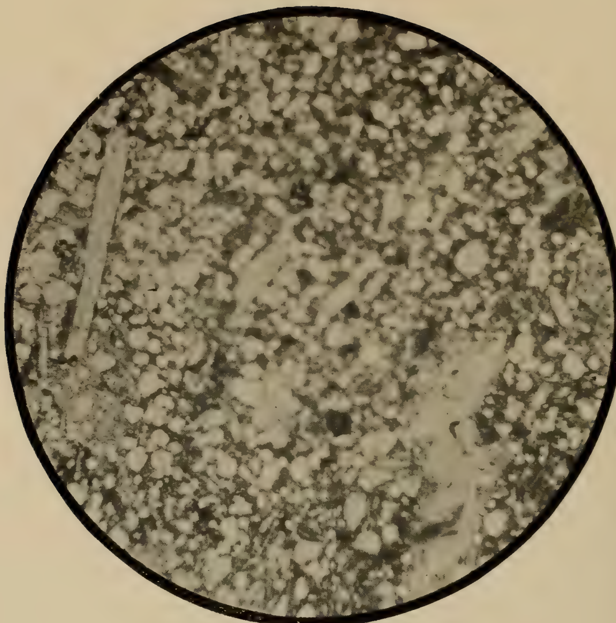

FIGURE 1.—WYOMINGITE FROM SOUTH TABLE

Round white minerals are leucite; small dark rods diopside; large crystals, phlogophite. The apparent groundmass is largely phlogophite charged with leucites. Actual field, 1 millimeter

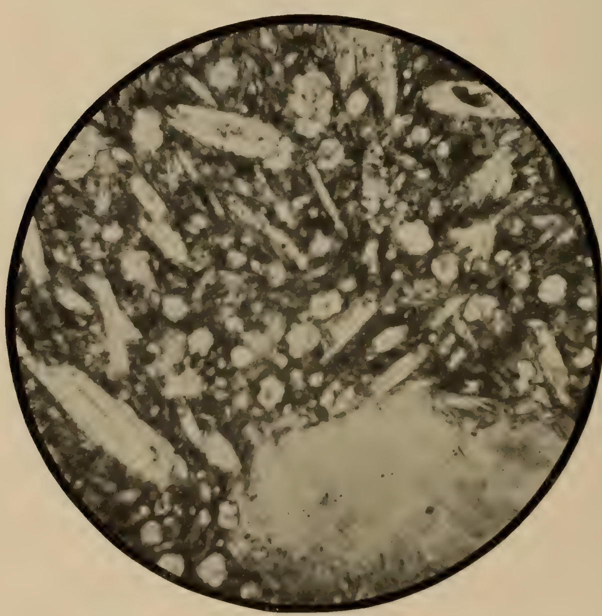

FIGURE 2.—COARSE WYOMINGITE FROM THE BADGERS TEETH AND CHARACTERISTIC OF THE DIKES

Round white minerals are leucite; rods are diopside; large elliptical mineral is phlogophite; dark groundmass is yellowish glass. Actual field, 1 millimeter. Locality, Badgers Teeth

PHOTOMICROGRAPHS OF WYOMINGITE

the only other minerals. In many cases the phlogopite is thickly set with included leucites. Figure 1 of plate 42 is a photomicrograph from a specimen taken from this locality. Should any visitor to the hills desire to collect wyomingite, this is the best of the mesas for the purpose. The rock occurs both as a dark, gray platy variety and as a light greenish, yellow one. The rock resembles the dikes much more strongly than it does the surface flows.

Remarks on North Pilot Mesa, North Table, and South Table

These three mesas, with nearly flat tops, occurring so near each other deserve some attention as regards their origin. North Pilot rests unquestionably on Tertiary rocks, and the two associated mesas rest on Laramie. At first one would be inclined to consider that they had been originally one large mesa, and that faulting had separated them. On careful examination, however, there was not the slightest evidence of faulting found about them. The talus from the three mesas would naturally meet in the gulch separating them, but there has not been time enough since their elevation to produce it in sufficient amount to reach the valley. Again, if they were due to faulting, there would naturally be some difference in the inclination of the mesas, when in reality there is very little. The only explanation to be offered for the origin of the latter two mesas is that they are intruded sheets. Each one must then have found a soft stratum which was capped by a hard one of some thickness. The lava must have been forced laterally as an intruded sheet, which was subsequently laid bare by erosion. That the latter view is true for South table there is little question. If North table is an intrusive, we must admit that the cover was slight, because of the amygdaloidal character of the rock. On the other hand, if North table is a surface flow, it must have been a later outbreak than North Pilot or else the topography must have been, at the time of the outbreak, much the same as now.

Volcanic Necks and Dikes Southeast of North Pilot Mesa

WORTMAN DIKE

Southeast of North Pilot a dike bears away to the southeast toward the three volcanic necks to be next described. We name it after Dr J. L. Wortman, now of the Peabody Museum, Yale University, in recognition of his work in Wyoming paleontology.

The rock of the dike is wyomingite. Phlogopite is the most prominent mineral present and forms phenocrysts in a dense groundmass,

consisting of diopside, leucite, apatite, and glass. In color it is light creamy brown, and it is very schistose from the parallel arrangement of the phlogopite. It is not particularly rich in leucite.

IDDINGS BUTTE AND DIKE

Iddings butte is a volcanic neck which forms an elliptical mass 200 to 300 feet long and 75 feet wide. It is located on a conical hill of Laramie strata, and consists both of solid rock and agglomerate, just as do the other necks. From the neck a dike bears away to the southeast for about 200 feet, level with the hill. We name these two exposures after Professor Joseph Paxton Iddings, of Chicago University, in recognition of his work in Yellowstone park and Crandall basin, Wyoming.

The rock is a dark gray orendite of a marked schistose character from the abundant parallel phlogopite. Under the microscope it reveals swarms of little leucites, much sanidine, considerable diopside, and a great richness in phlogopite. The agglomerate is likewise a dark gray rock, and consists partly of orendite and partly of fragments of sedimentaries.

WEED BUTTE

This lies in the general direction of the strike of Iddings dike and is another neck resting on a rounded hill at a lower elevation than the last. The rock has not been examined with the microscope. We name it after Mr Walter Harvey Weed, of the United States Geological Survey, in recognition of his work in Yellowstone park.

HALLOCK BUTTE

Beyond Weed butte to the southeast is another neck rising from a low hill. The rock has not been examined with the microscope. We name this exposure after Professor William Hallock, of Columbia University, formerly physicist on the Yellowstone Park Survey.

Talus Covered Hills

ENDLICH HILL

Northeast of Iddings butte there is a talus covered hill, where the blocks of lava are very large and have the appearance of being the residue of a former sheet or dike, but no rocks in place were discovered. This hill has a diameter of about a half mile at its base and is well covered with the blocks. The rock has not been examined with the microscope. We name it Endlich hill after the late Dr F. M. Endlich, of the

FIGURE 1.—ORENDA MESA

View from north, with cones of Zirkel mesa in background

FIGURE 2.—BLACK ROCK MESA

FIGURE 2.—STEAMBOAT MESA

View from south with a ridge of sedimentary shale on the left, over which are drifting the sand glaciers to form dunes at the foot and to the east

ORENDA, BLACKROCK, AND STEAMBOAT MESAS

Hayden Survey of the Territories, and one of the first geologists to visit the Leucite hills.

HAGUE HILL

Southwest of the necks above mentioned there is a second talus covered hill which was not visited. This is much larger and is also much higher than the one just described. Whether or not it contains a portion of a sheet in place can not be definitely stated. There is no scarp about it, and from the distance of a half mile nothing but talus blocks were visible. We name it Hague hill after Mr Arnold Hague, the chief of the Yellowstone Park party.

Orenda Mesa

This is a large mesa, some 3 miles north of Zirkel mesa, and has not hitherto received sufficient attention. It is an irregular flow or series of flows, bounded with a scarp, but it also has three cones and a considerable surface of an undulating nature. It is nearly a mile in length from the northwest to the southeast and about a half mile in width. It is illustrated by figure 1, plate 43. The highest cone is approximately 7,750 feet above tide. The other two to the northward are considerably lower. While the scarp is in places quite high, there are several points near the head of slight gulches where it can be ascended with ease and where the first flow of lava seems to have been much thinner than in the average exposure. The cones were not ascended, but about their bases the yellowish pumiceous rock was found, such as occurs at cone number 1 on Zirkel mesa; otherwise the surface flow on the south edge of the mesa was a very fine grained dark rock, having a conchoidal fracture. When found in large fragments it would ring like a bell when struck with a hammer.

After studying this mesa from Zirkel mesa and also from the trail that leads to the west of it, we concluded that it was highly probable that there were five flows of lava, which from a distance seemed to be distinguishable, but which presented a very complex structure. Apparently on the first lava flow there came a second. Either later or at the same time with it an old ring seemed to have developed. Then resting on number 2 come successive terraces of 3, 4, and 5, the last forming a shoulder near the top. The highest cone seems to be the residue of this weathered complex. A picture of Orenda mesa is given in figure 1, plate 14, volume 7, of this Bulletin.

The name Orenda mesa is taken from the state map of Wyoming, which has been issued by the United States Land Office, but we do not know its derivation.

Our specimens have been obtained from the southeastern portion of the mesa. Under the microscope all proved to be orendite. They contain leucite, sanidine, diopside, phlogopite, and hornblende, and are normal representatives of this rock.

Black Rock Mesa

This is the most easterly outlier of the Leucite hills, and is a very symmetrical mesa, which rises 500 feet above the valley at its base. The slopes are talus covered, as are those of all the mesas of this type, and just above them rises the vertical wall of the scarp. This exhibits from a distance polygonal columns suggestive of the characteristic basaltic structure; but on near examination the resemblance is less close, although the columns are obviously due to parallel, vertical joints (see figure 2, plate 43). The scarp is upwards of 50 feet high in places, and the only possible opening through which one can reach the crest is found on the northwestern slope, where by hard and difficult climbing one can gain the upper surface. This mesa, like several others, appears to be nearly level on top; but in reality there is a broad depression through the center on an east-and-west line, which causes the north-and-south sides of the scarp to rise considerably above the average level. The leucite rock varies greatly in texture. The cap of the mesa is a fine grained rock, shading from a gray to a reddish color, and weathering very slowly. Near the base of the scarp on the north side the rock is soft, porous, and in many places resembles a tuff, which, when breaking up, forms roundish talus blocks very different from those composed of the harder rock. This mesa is about an eighth of a mile in diameter, and has an approximate elevation of 7,600 feet. It rests on the Laramie Cretaceous, and has a diameter at its base of about a half mile. The name Black rock has long been locally used for the mesa.

The fine grained variety of rock is chiefly wyomingite, but in one slide of the cellular portion a little sanidine also appeared. Leucite is the chief feldspathic mineral, and with it diopside, phlogopite, subordinate hornblende, and rutile all occur. Olivine appears as an inclusion in the phlogopite. In one slide is a pale green crystal of high relief and almost if not quite isotropic as cut. It strongly resembles a spinel, and fails to give a recognizable interference figure. More thin-sections would probably show orendite also in this mesa.

Steamboat Mesa

In many respects this is the most impressive of all of the mesas. As early as 1875 F. M. Endlich, of the Hayden Survey, visited it and named

the highest cone Essex mountain. At that time it was simply referred to as basalt and was mapped as being about ten times its real size. From the great sand dune country on its south it rises very abruptly for 1,100 feet to the edge of the escarpment, which is 150 feet below the highest cone (see plate 43, figure 3). In climbing it from the south and the most inaccessible side, one passes over a thin band of Laramie, above which may be a thin bed of Wasatch, for the latter is well exposed only a few miles to the north. Along the mesa it has been probably covered with a heavy talus of sedimentary rocks. Above the horizon where the Wasatch should be found there are well developed beds of Green River shale, and above these a thin bed of Bridger. From the latter beds we obtained typical, siliceous oolitic rock and also an ostracod limestone, which occurs in the Bridger wherever found. From the base of the lava escarpment the talus slopes are exceedingly steep and in places read from 30 to 35 degrees, just about at the limiting angle of repose. On the north of the mesa there are great tablelands that have been developed out of the Green River shales, and occasionally there are remnants of the Bridger beds, and only 6 or 8 miles farther north the Bridger beds reach a thickness of about 1,000 feet.

From east to west this mesa has a length of between 2 and 3 miles, and its greatest width is approximately a mile. The southern face is a vertical escarpment rising from 25 to 60 feet, and it has a circular outline. On the north it is deeply dissected and there are gulches extending into the lava mass for a distance of over a half mile, and between these there are long arms of the flow projecting to the northward out on the Tertiary beds. From the northern side the mesa is quite accessible and often affords pasturage for flocks of sheep or herds of cattle and horses. The surface is quite irregular, more so than any other of the mesas except Orenda. There are broad gulches with a northern trend which head near the southern side, and along these there are small groves of spruce and pines interspersed with quaking asp.

From the surface of the mesa three apparent cones arise. They are not, however, in any case pumice or fragmental aggregates, but are hard sheets of lava, either marking the source of vents with huge blisters above the point of eruption, or else they are the unweathered nuclei of thick sheets, elsewhere reduced by erosion to lower levels. The cones were numbered as follows: South cone number 1, middle cone number 2, northwest cone number 3.

The lava occurs in two distinct and easily recognizable flows, each of which is about 30 feet thick. The contact is marked by a black scoriaceous crust on the lower surface of the upper flow, which gives all desirable evidence of a quick chill. Irridescent hues play over the dark scoria

just as on the Vesuvian lavas, and remind the observer most strongly of some of the familiar phenomena of the Neapolitan volcano. It would appear as if the second flow had followed the first after a comparatively brief interval of time. The flows are not otherwise greatly contrasted. They each have amygdaloidal and dense bands. The amygdules are sometimes of altogether extraordinary size, being 3 to 6 inches long and half as broad. They are occasionally lined with beautiful crusts of chalcedony.

The rock of this mesa is prevailingly, if not entirely, wyomingite. Our specimens, gathered from the east and west ends and from cone number 1, are of this type. There may be a little sanidine at the southwest point, but it is rare and doubtful. Leucites are in great richness; diopside is comparatively scarce. There is a little hornblende and considerable phlogopite. Rutile and apatite complete the list. Calcite appears rarely in the amygdules. The black scoria is of great interest. In thin-section it presents a gray green glass with myriads of little leucites scattered through it, precisely as in some Vesuvian scorias. We have seen no similar rock anywhere in the hills. It has doubtless been caused by the quick chill at the under side of the flow. The scoria may be collected along the old and partially completed road at the southwest corner of the mesa.

Badgers Teeth

These remnants of an old volcanic neck seem not to have been observed by any geologist previously to our trip. They lie off the regular trails, and are pretty well hidden in a gulch. They constitute five projecting, tooth-like masses, ranged along an east-and-west line. The two on the east are larger than the three on the west (see figures 1 and 2, plate 44). From a valley eroded in Laramie sandstone a conical platform of the same rock rises to a height of 50 feet. The sandstones strike north 70 degrees east magnetic and dip 5 degrees north. A talus of leucite rock then ascends with a steeper angle about 75 feet farther, and from this the two larger "teeth" project 20 or 30 feet additional. The hill is from 500 to 600 feet in diameter at its base. The projecting masses consist partly of a green, volcanic agglomerate and partly of solid eruptive rock. The mass of the two larger teeth consists of about half of each. Before the explosive activity which gave rise to the agglomerate there must have been a solid dike, because the boulders of the agglomerate are chiefly of eruptive rock themselves, and the interstices are filled with tuff or mud precisely as at the Boars tusk. The dike is a dense drab rock, which in places is amygdaloidal. The amygdules contain crystals of aragonite, which, except for the chalcedony of Steamboat mesa and

FIGURE 1.—BADGERS TEETH

Volcanic neck as seen from the south

FIGURE 2.—LARGEST OF BADGERS TEETH, SHOWN IN FIGURE 1

View taken from north. The rock is volcanic agglomerate

BADGERS TEETH

the niter observed by Doctor Cross, is the only secondary mineral we have observed in the amygdules. The aragonite occurs in platy crystals and in tufts of needles. In the field we thought the needles to be some zeolite, but they were kindly determined to be aragonite by Dr Austin F. Rogers, of the Department of Mineralogy, Columbia University. The dike also contains many inclusions of sandstone and shale.

It would appear as if a dike had penetrated the Laramie in an east-and-west fissure and had chilled. Explosive eruptions then broke out along it and developed the agglomerate, into whose substance the dike rock entered. The phenomena are similar to those which are met at the well known Annie Lee mine, Victor, Colorado. It is, however, also possible that older eruptive rock than the dike existed on the surface and was blown to fragments by the explosive action, so that its boulders fell into the vent. The agglomerate must then have been penetrated by the dike or dikes, and all the rest of the sheet must have been removed. The first hypothesis seems much the most probable. Whether the dike rock is all the same mass or whether it forms several dikes is a fair question. The general bearings of the exposures do not seem to run together necessarily, but no continuation of the dike or dikes can be found outside of the cone itself. In fact, the extremely limited character of the exposure brings one irresistibly to the conclusion that it is an elongated volcanic neck built up in a short fissure.

A third hypothesis may be suggested. It is possible that a small mesa with a cone once existed over the present neck, and that in this way the agglomerate was formed. If so, we have an illustration of the conduits which have fed the mesas.

We name these exposures the " Badgers teeth " on the analogy of the larger " Boars tusk," to be next described.

The dike is wyomingite and one of the best examples of this rock in the hills. The leucites are large and abundant. The diopsides are also unusually large and well formed. The phlogopite has its own six-sided boundaries. There is abundance of a yellow glass present in which the other minerals are embedded. A very few stray sanidines were detected, so that it can not be said that the rock lacks this mineral entirely. Apatite is also present. The rock is practically identical with that at the Boars tusk and Wortman dike. It is illustrated by figure 2 of plate 42. The figure brings out the coarse crystalline texture of the dikes as compared with the flows.

Boars Tusk

This extraordinary volcanic neck is one of the most striking and interesting of all the exposures in the region. It is in the middle of the

valley of Killpacker creek, 25 miles or so north of Rock springs. The valley is 5 or 6 miles wide, and from its central flat the pillar of the Boars tusk arises like a monument. It is a double spire because of a cleft which is due to a fault and pinch that traverses the neck in a north-and-south direction (magnetic) and renders very platy the constituent rock. On map 3 of the atlas of volume xii of the Hayden Survey the Boars tusk is called "The Sentinel." F. M. Endlich, in volume xi, page 133, speaks of it as "an isolated needle of basalt known as Rock point." We adopt the name now current in the region.

As shown in the illustration, figure 2, plate 45, the Boars tusk consists of three parts. The base is a very flat cone, all covered with fine talus, lying at an angle of slope of about 17½ degrees. The diameter of the base is just about four times the total altitude of the tusks. This frustum has a vertical height of 100 feet. On it is set a frustum of coarser talus, having a slope of 25 degrees, and continuing to the solid rock, which it encircles with an irregular upper contour. Its vertical height is about 75 feet. It consists largely of huge fallen boulders from the tusk, with which are some finer materials.

From this last frustum the tusk proper continues almost vertically upward, but by scrambling up the cleft between the two cusps, and winding around, one could by some more or less risky work almost, if not quite, ascend the lower cusp. The height of the higher cusp is 360 feet above the plain, as shown by solving a simple set of triangles, whose altitudes could be determined by the aneroid and whose angles necessary to solution were obtained by taking vertical angles with a Brunton pocket transit.

The material of the tusk is chiefly eruptive agglomerate and tuff, but the whole mass is penetrated by the north-and south dike, whose width is from 30 to 50 feet, and which is sheeted by the fault. The dike itself contains many inclusions and much resembles a hardened tuff. The boulders of the agglomerate are partly a cellular, eruptive rock and partly fragments of shale and sandstone. Some of the shale is believed to have been derived from the Green River beds, as it is exactly like their typical representatives. Since the tusk and its frustra rest on Laramie, and there are no Tertiary beds visible, it would follow that the explosive vent broke through Green River strata, which must have formerly rested on the Laramie at this point, and whose materials, after being blown into the air, settled again into the vent and became involved with the tuffs and breccia, now left in relief by the erosion of their former walls. Consequently the outbreak was later than the Green River, and the Green River beds have retreated far to the westward in the interval of time since it occurred. There must have been during a part of this time a

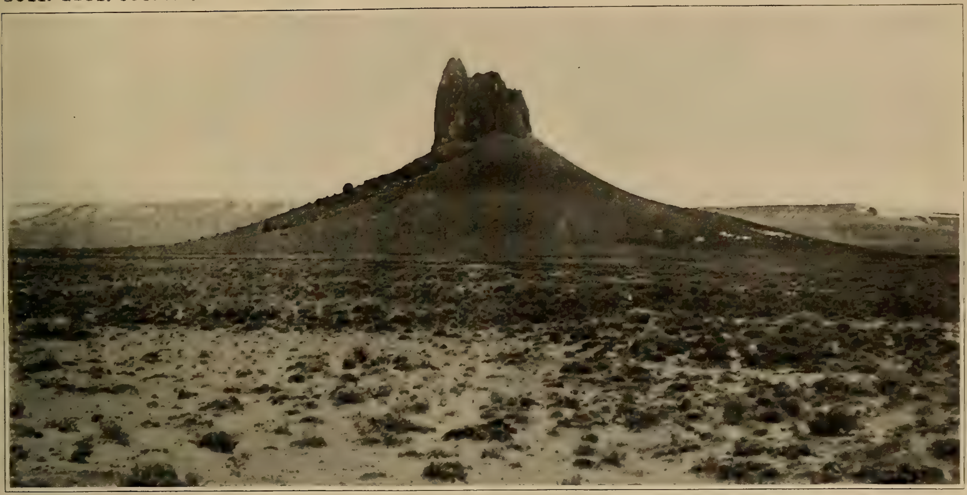

Figure 1.—Boars Tusk—A Volcanic Neck

As seen from northeast. The distant mesa is the escarpment of Green river shale, on which rests Pilot mesa

Figure 2.—Boars Tusk

As seen from Matthew hill and at a distance of one mile.

BOARS TUSK

larger stream in this valley than the present Killpacker creek. In the preexistence of solid lava which furnished most of the boulders, it is necessary to believe by the same reasoning as is outlined above under the Badgers teeth. We also conclude that a dike closed the eruptive activity and forced its way through the neck.

The dike at the Boars tusk, as has already been noted by Doctor Cross, is wyomingite, and only differs from this rock as found in the flows by the minor textural features which are characteristic of the dikes. Leucite is the chief mineral in relatively large development. The diopsides are likewise large. Phlogopite often forms composite crystals. The yellow glass of the Badgers teeth is lacking.

Doctor Cross has noted some slight contrasts between the leucite rock of the agglomerate and that of the dike, mainly in the presence of large apatites and leucites. He also detected a few small biotites.

Matthew Hill

This is a low rounded hill, located about a mile a little east of south of Boars tusk. From a distance no one would surmise that it was in any way connected with the leucitic exposures. At its base it has a diameter of about a quarter of a mile and rises 50 feet above the sandy waste which surrounds it. There are small fragments of leucite rock scattered about its base and also, to some extent, on its slopes. On the crest of the hill there is a narrow dike 60 yards in length and having a strike nearly northeast and southwest. This is separated from a small dike having a course nearly at right angle to it by 15 feet of sandstone. A short distance beyond the cross-dike there are two other dikes having a strike of south 10 degrees west of north. The first one has a length of 22 yards and is separated by 10 feet of shale from the second, which extends nearly to the base of the hill. The rock from all of these dikes is mostly schistose, but there are occasional pieces of agglomerate, such as is found at the Boars tusk and the other volcanic necks in this region. The hill is unquestionably a volcanic neck that has suffered excessive erosion which has not only cut down the leucite rocks, but also the surrounding Laramie sandstone and shales.

We take pleasure in naming it Matthew hill, after Dr William Diller Matthew, of the American Museum of Natural History, whose work has thrown much light on the paleontology and development of the so-called lake beds of the Tertiary.

The dikes are wyomingite in an advanced stage of decomposition. The slides show spots of alteration, which are not infrequently distributed through them and which are filled with some secondary and feebly re-

fracting mineral, probably a zeolite. Leucite, diopside, and phlogopite make up the fresher portions.

Pilot Mesa

This is located on the large plateau of Green River shales, about 12 miles west and north of Rock Springs. The plateau has an elevation of about 1,000 feet above the town of Rock Springs, and is bounded on the east and south by very precipitous bluffs. The mesa is situated about 3 or 4 miles back from the eastern edge of the plateau and rises to a height of 350 feet above the comparatively level surface. The talus slopes are quite smooth and are in great contrast with the slopes of the other mesas, where they are in part impassable. They are also more gentle, and it is seldom that one finds a fragment of the eruptive cap of any size until the vertical escarpment is reached. The escarpment varies from 25 to nearly 75 feet in height, being lowest on the eastern and highest on the western side. The only place noted where one could reach the top was through a narrow crevice on the eastern side, which leads to a broad gulch, which in turn conducts one westward nearly to the center of the mass. In shape this mesa resembles a gourd with the neck extending to the westward. It is less than a quarter of a mile in length. The greatest diameter is east of the center, and is less than an eighth of a mile. The surface is gently undulating, but gradually rises from east to west. The highest point is very near the edge of the scarp on the west, and is 7,650 feet above sea-level. From the lowest exposed rock to the top on the eastern face nothing but a yellowish schistose variety of eruptive was noted. This is fine grained, somewhat vesicular, and heavily charged with small angular fragments of Green River shale. The mass of the mesa is schistose, and the schistosity is parallel to the bedding planes of the underlying sediments. On the highest point there is apparently a second flow that is less schistose, but more porous and of a grayish green color. Judging from the slight development of large talus blocks and the absence of fissures about the escarpment, this mesa must rest on a very firm base, which is probably a hard band in the Bridger. The fine talus has so obscured everything that there are no exposures of sedimentary rocks about the mesa, so far as could be discovered. In fact, the talus had spread out to a considerable distance from the base of the mesa. It is quite probable that Pilot and Steamboat rest on the same formation, if not on the same stratum.

Pilot mesa presents a different rock from any of the other exposures. It is the type locality for the madupite of Cross, and, so far as rocks have yet been studied, is the only place where this interesting rock

FIGURE 1.—MADUPITE FROM PILOT MESA

Groundmass is of glass; rods are diopside; black dots are perofshite. Actual field, 1 millimeter

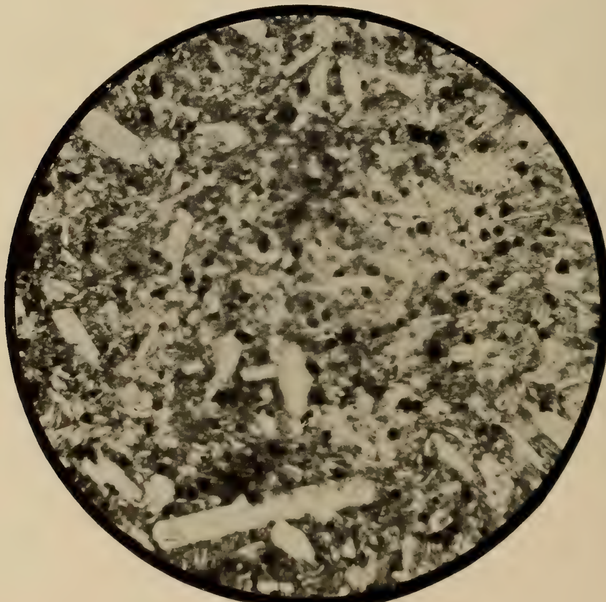

FIGURE 2.—MADUPITE FROM PILOT MESA

Description of minerals the same as in figure 1. Actual field, 1.5 millimeter

MADUPITE FROM PILOT MESA

occurs. As soon as one looks at the slides one is impressed with the basaltic character of the rock, even though this impression would never be given by the hand specimens. The latter are light cream to drab color and of pronounced platy structure. They are usually streaked with alteration products. Their specific gravity, greater by .15 to .18, as compared with that of the leucite rocks, is marked when one lifts them. The slides show abundant dark grains of perofskite, besides which diopside is the principal mineral. Phlogopite is, however, also present as is interstitial glass. Leucites are doubtful, but we believe that small, imperfect ones occur. The rock is closely related to the ordinary augitites. It is illustrated in plate 46, figures 1 and 2.

Tabulation and Summary of Exposures

Name.	Character.	Underlying beds.	Altitude.	Number of cones.
1. Zirkel mesa........	Surface flows......	Laramie......	7,825	5
2. Emmons mesa.....	Surface flow........	Laramie.......	7,700?	1
3. Osborn mesa.	Surface flow.......	Laramie.......	8,200?	0
4. Cross mesa.........	Surface flow........	Laramie.......	7,850	1
5. Hatcher mesa......	Surface flow.	Laramie.......	7,640	0
6. North Pilot mesa..	Surface flow.......	Green River?..	7,650	0
7. North Table.......	Surface flow?.......	Laramie.......	7,515	0
8. South Table.......	Intruded sheet.....	Laramie.	7,350	0
9. Wortman dike.....	Dike...............	Laramie	7,350	0
10. Iddings butte......	Volcanic neck.....	Laramie..... .	7,000?	0
11. Iddings dike.......	Dike..	Laramie.....	7,000?	0
12. Weed butte........	Volcanic neck. ...	Laramie.......	7,000?	0
13. Hallock butte......	Volcanic neck.....	Laramie........	7,000?	0
14. Endlich hill.......	Residual sheet.....	Laramie.......	7,250	0
15. Hague hill.........	Residual sheet.....	Laramie........	7,500?	0
16. Orenda mesa	Surface flows.....	Laramie.... .	7,700	3
17. Black Rock mesa...	Surface flow........	Laramie........	7,500	0
18. Steamboat mesa...	Surface flows.. ...	Bridger........	7,750	3
19. Badgers teeth......	Volcanic neck... .	Laramie.......	7,200	0
20. Boars tusk...... ..	Volcanic neck.....	Laramie........	6,950	0
21. Matthew hill.....	Volcanic neck.....	Laramie........	6,700	0
22. Pilot mesa.........	Surface flow.	Bridger..	7,650	0

From this tabulation it appears that the Steamboat and Pilot lavas rest on the Bridger beds, and, as the eruptives are surface flows, they must have been poured out during or after the Bridger epoch of the Eocene. Now eight others of the exposures are cellular surface flows. Their very open, amygdaloidal texture makes it impossible to consider them anything else.

They have, moreover, cinder cones of volcanic tuff and breccia, and, although resting on Laramie strata in many instances, they never can

have been emitted in Laramie time, because this would imply their burial and resurrection, an impossibility for surface flows with fragmental cones. On the contrary, it is reasonable to conclude that they are all post-Bridger. It follows also that not only are they post-Bridger, but they must have been poured out, at least at Zirkel, Emmons, Cross, Osborn, Black Rock, and Orenda mesas, after the Bridger and Green River beds, which once covered these localities, had retreated because of erosion so as to uncover the Laramie where the mesas now appear. It is therefore evident that they are post-Bridger. The question arises as to how much later.

While it is very difficult to determine the exact age of the eruptions, they are at least late Tertiary. From recent investigations it has been determined that the Oligocene beds that are so prominent along the eastern base of the Rocky mountains extended westward as far as Green river. Oregon buttes, which are great landmarks south of South pass, are capped with Oligocene, and at an elevation much lower than their crest good remains of a titanotherium have recently been discovered. This leads us to believe that originally the Oligocene covered a vast area in this region, and that the greater part of these beds had been removed by erosion before the leucitic eruptions, for in no place were these eruptive rocks found higher than the Bridger. It is evident, then, that these eruptions were post-Oligocene, and it must have been well along in the Miocene, if not during the Pliocene. They can not be considered more recent than the Pliocene, on account of the warping of the mesas, which was no doubt done during the great Pleistocene uplift of the Rocky Mountain region.

One important consideration affecting the time of their intrusion is this: The cones of tuff and breccia which surmount the mesas can not have been very large ones, because, if we continue their present arcs to complete circles, the latter are not great. Yet considerable fractions of the cones still remain. A protracted period of exposure, geologically speaking, would have destroyed these incoherent piles, even in an arid climate.

Erosion has, however, eaten well back into the sheets, and has greatly dissected them along the northern slopes, and it is evident that very considerable amounts of work have been accomplished since they chilled. The points made above in discussing the Boars tusk also bear on this question.

Former Connections of the Mesas

The question of the former connection one with another of the mesas would naturally arise in the mind of an observer. To some degree they

have probably been broken apart by erosion. Thus Zirkel mesa and Emmons mesa were no doubt originally one flow, since they are now separated by a relatively narrow gulch and front each other with escarpments that match for nearly 2 miles. That, however, the others were connected is improbable. As between Zirkel mesa and Orenda mesa the interval of erosion is so great as to make the supposition that they ever were united altogether improbable. Of all the rest much the same holds true. The intervening gaps and stratigraphical positions preclude the supposition. On the contrary, we are justified in picturing in our imaginations a landscape which erosion had brought somewhat toward its present conditions. In the midst of this a number of eruptive centers broke out, now represented by 22 separate exposures which remain.

There appears to have been some tilting and disturbance of the surface flows since their eruption, because Zirkel mesa no longer lies flat. Its southern edge is as high as the summits of the cones at its northern side and corresponds to the dip of the underlying Laramie. The flows also rise toward Emmons mesa on the west. These are positions which a molten surface flow could not well have assumed unless it had flowed down hill from sources outside the present exposures. In the latter event we ought to find the dikes or vents which fed them, and of these there is no trace.

There has also probably been some minor faulting, to which may be attributed the small escarpments and gulches on the western portion of Zirkel mesa. The break of a fault may have located and aided the formation of the gulch now existing between Zirkel and Emmons mesas. Faults may be demonstrated in the Laramie outside the flows of leucitic lavas. Thus one is very pronounced at the western side of the entrance to the valley of Fifteen-mile spring on the north side of Zirkel mesa.

As already noted, a fault has certainly broken and sheeted the rock of the Boars tusk, and the surface of Steamboat mesa is very irregular, being broken by gulches and hillocks, which are probably not all due to erosion pure and simple. There are so few springs that to subterranean circulations and consequent caving it is not easy to attribute much efficiency.

In some of the smaller mesas disturbances seem generally to have failed. Thus on Cross mesa the lava sheet is a dead level, so far as the eye can detect, for at least a mile west of the cone.

The Cones

The cones present to the observer some of the most striking features of the region. They are of two kinds, fragmental or cinder cones and

blisters or swellings of solid lava. Nearly all are of the former character, but cone number 5 on Zirkel mesa and the three on Steamboat mesa are of the latter type. We are inclined to believe that the latter are protuberances which mark the places where the more or less viscous eruptive welled out to the surface and from which it spread in the flows. There seems no other reasonable way in which to account for so great a local thickening. Aside from the lava cones there appears little evidence as to the channels through which the molten rock reached the surface, unless it was so fluid that it spread in all directions from the supply fissure without leaving an elevation to mark the location of the latter.

The cinder cones in instances are markedly semicircular, and impress the observer as being the uneroded arcs of formerly complete circles or rings. They rise abruptly from the fairly level mesa and were built up by explosive outbreaks which yielded fragmental products. The cone on Cross mesa, for instance, is nearly or quite a semicircle, and others on Zirkel mesa show the same character. Again, we may have merely a conical heap of fragmental debris. In the latter case, and according to the hypothesis of the original ring like cone, we are forced to infer more complete erosion than in the case of the semicircular cones, but we have speculated somewhat while studying over these phenomena as to the possibility of the original production of a predominant deposit of ejectamenta on one side of a vent either from inclined conduits or from prevailing winds. If so, it would not be necessary to assume the entire removal of one side of the ring.

The interior area of the semicircles is so buried in fragmental matter as to be in all cases fully concealed. We can not but believe, however, that under them are volcanic necks like the Boars tusk and the Badgers teeth. The latter may once have been capped by surface flows and cones.

Nature of the eruptive Mesas

The eruptive rock of the mesas is in all cases, except perhaps the two tables, clearly of the nature of surface flows. It is strongly amygdaloidal with the cavities drawn out in the direction of the flow. From even the central portions of a flow it is almost impossible to secure solid specimens; nevertheless it is true that cellular streaks alternate in the faces of the escarpments with more compact ones.

The tabular crystals of phlogopite which are universally present in all the exposures are in the surface flows ranged in parallel and flat alignment, and when abundant give the rock the appearance of a mica schist. In fact, its resemblance to a mica schist is at times extraordinarily close,

and it is in great contrast in this respect to any other eruptive known to the writers, unless it be certain minettes.

In the dikes associated with the volcanic necks the rock is naturally more compact than in the surface flows, but in the two exposures the Boars tusk and the Badgers teeth it is not entirely devoid of amygdules.

Do the different flows differ in chemical and mineralogical composition? That there is considerable variation within narrow limits among the rocks of the several mesas, buttes, and necks both Doctor Cross and one of us have earlier shown. All the variations are due to differing relative amounts of practically the same ingredients, namely, leucite, sanidine, diopside, phlogopite, a rare amphibole, rarely aegirite, apatite, and unindividualized base. The last named, of course, introduces marked contrasts in texture. Diopside, phlogopite, and apatite are common to all the exposures, but any one of the others may entirely fail. No attention has been previously given to the question as to whether this variation, if occurring in the same mesa, is present in the same or different flows. In our collecting we have endeavored to give emphasis to this feature, and have concluded that there is variation in the same flow.

Secondary Minerals

Very rarely secondary minerals have formed in the amygdules. As a rule, they are empty. Doctor Cross has reported a potash niter, and we have found chalcedony at Steamboat mesa and aragonite at the Badgers teeth. On the surface of North Pilot there are numerous small concretions and crusts of a mineral rich in phosphoric acid containing calcium, magnesium, and aluminum of varying percentages. Thus far it has been impossible to refer it to a mineral species. This same mineral is occasionally found in the cavities of the porous varieties of the leucite rock.

Another mineral deposit which is frequently to be noted around the escarpment is a crust produced by mountain rats. It is now being investigated.

Sand Glaciers and Dunes

To the southwest of Steamboat mesa a ridge runs away, leaving a pass between the two. Over this pass great volumes of white sand are constantly being blown from the regions to the west by the prevailing winds, which are westerly. The sand sweeps up over the crest from a great stretch of barren dunes running toward Killpacker creek and rolls down

the eastern side of the ridge in forms that stimulate glaciers with great vividness. Figure 3 of plate 43 is from a photograph. The sand has been derived from the erosion of the sedimentaries, but when placed under the microscope it shows distinctly its wind-blown character. The dunes are from 3 to 6 miles wide and, with but few interruptions, extend eastward to the North Platte river.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 14, PP. 337-352, PLS. 47-48 SEPTEMBER 2, 1903

PALEOZOIC CORAL REEFS

BY AMADEUS W. GRABAU

(Read before the Society December 30, 1902)

CONTENTS

INTRODUCTION

During the prosecution of field work in the Hamilton limestones of Michigan, I became aware of the existence of well marked isolated coral mounds or hillocks in the otherwise stratified and almost unfossiliferous limestones. These coral hillocks are particularly well exposed in the vicinity of Alpena, where several quarries have been opened in them. In his survey of the region Rominger spoke of them as "bubble-like" upheavals of the strata. Recent favorable sections in the quarries permitted the study of these hillocks in detail, when their reef character became apparent. A brief account of the reefs was published in the American Geologist, September,* and a more extended one, with a cross-section, in the annual report of the Geological Survey of Michigan for

* Vol. xxviii, 1901, p. 182.

1901.* Since then I have received from Dr Carl Wiman a copy of his paper on Siluric coral reefs in Gotland, published in 1897, in which he describes reefs of a similar character. These will be referred to again. Coral reefs of similar types have been described also by Dupont, from Devonic and Carbonic limestones of Belgium. During the summer of 1902 I had an opportunity, in connection with my study of the Michigan limestones, to visit the Niagara coral reefs in the vicinity of Milwaukee, and later I found similar structures in the Onondaga limestones of Williamsville, New York. The examples studied may now be described in detail.

Description of Coral Reefs

HAMILTON REEFS OF ALPENA, MICHIGAN

The reefs in the vicinity of Alpena are best exposed in the quarries opened in the Alpena limestone, which has a thickness of about 35 feet and is the middle member of the Hamilton or Traverse group in the Thunder Bay region. Reefs occur in higher and, to some extent, in lower strata of the group, but none of these are well exposed.

In outline the reef is roughly dome shaped with slopes sometimes as great as 30 or 40 degrees. The height of the dome is equal to the thickness of the limestone stratum, about 35 feet in this region, and the greatest diameter, which is near the base, is perhaps several hundred feet. The chief reef builders represented are Favosites, Acervularia, and Stromatopora, which form the main mass of the reef, while between them are found the smaller corals and bryozoa, as well as brachiopods, crinoids, and a few other types of organisms. There is an absence of stratification in the central reef mass, the structure being exceedingly irregular. Between the corals and shells is found a filling of coral sand, which generally consists of rather coarse fragments with a predominance of crinoid joints. Solution and recrystallization have not infrequently taken place, with the result that dogtooth spar is of common occurrence.

The coral heads are generally of large size; sometimes they are overturned, but most of them appear to lie in their normal position of growth. In some places the crystalline coral sand forms most of the reef exposed, the large coral heads being scattered through the sand. The sand shows no stratification so far as observed. The sand filling the cavities of the reef is generally much coarser than that forming the normal sediments on its flanks. In places at some distance from the center of the reef the rock consists of a breccia made up of brachiopods, bryozoa, and the small branching corals, with a plentiful interspersing of the joints of crinoid stems.

* June, 1902, p. 176.

CORAL REEF IN ALPENA LIMESTONE

View taken in Collins' quarry, Alpena, Michigan. To the left of the center is the massive unstratified reef; stratified clastic limestones on right, dipping steeply next to the reef, then becoming horizontal; other steeply dipping strata on left. Note position of figures

VIEW OF REEF SHOWN IN PLATE 47

View taken from the position occupied by the right hand figure in plate 47. The figure on the left occupies the same position as in that plate. Steeply dipping strata of clastic limestones are shown on both sides of the reef

On the sides of the reef the bedded strata, which consist chiefly of consolidated crinoid and coral sand, dip away at high angles. Measurements in one of the quarries in Alpena (Collins') showed an inclination of 28 degrees near the reef, falling rapidly to 14 degrees and then more gradually to 2 degrees, which is the normal dip of the strata. Throughout the marginal zone there is an interlocking of organically formed and fragmental lime rock, indicating a periodic spreading outward of the reef and a subsequent overwhelming of each expanded rim by fragmental deposits. These spreading fringes of the reef consist mainly of the smaller branching corals and of bryozoa, which at times extended far out on the foundation of coral sand. In fact, it is these expanded rims, formed when erosion temporarily ceased and when only fine silt was

FIGURE 1.—*Diagrammatic Cross-section of a Devonic Coral Reef.*

From Traverse group, Alpena, Michigan, showing central reef portion of coral heads, with coral-sand filling, and bedded clastic limestones (calcarenites, etcetera) surrounding it and dipping away from it. At intervals the reef spreads out, dividing the bedded limestone.

deposited, that mark the division of the fragmental limestone into tiers or beds. The beds themselves, often several feet thick, are generally unfossiliferous, though here and there a more or less perfectly preserved fossil may be found. For the most part, however, organic remains, more or less finely ground up, make up the beds of limestone. They are, however, commonly separated by thin shaly films, which occasionally may have a perceptible thickness. It is during the formation of these separating layers, which mark the periods of non-deposition of the fragmental lime sand, that the organisms of the reefs creep outward over the stratified beds, and it is here, as every collector knows, that fossils must be looked for.

Chemical analyses of the rock show that the purest limestone is found in the center of the reef, where the per cent of $CaCO_3$ is not infrequently over 99.

REEFS OF THE TRAVERSE BAY REGION

No actual exposures of reefs occur on Little Traverse bay, but in the cliffs between Petoskey and Bay Shore a number of sections of marginal zones of reefs are furnished. In these sections the rock is chiefly a

uniformly grained fragmental lime sandstone (*calcarenite;* see postea), or consolidated coral sand, with occasional beds composed wholly of crinoid fragments. Fine grained beds of lime-mud sand (*calcilutite*) are also found. At intervals the section passes near enough to the reef to show the presence of numerous coral fragments. The fragments are all much worn and broken, and are embedded as boulders or pebbles in the stratified lime sands. Where they are abundant they constitute a veritable coral conglomerate (*calcirudite*) such as may be found near the borders of modern reefs. Good exposures of such conglomeratic beds are found in the quarries and shore sections east of Petoskey, where these coral pebbles (chiefly Acervularia and Favosites and the hydrocoralline Stromatopora) give the rock a strikingly mottled appearance. Not infrequently seams of carbonaceous material separate some of the layers of limestone, and in these plant remains are not uncommon. Within the thicker beds themselves the phenomena of contemporaneous erosion, of the wedging out of strata, and, occasionally, of cross-bedding and ripple marks are met with. Indeed, all the phenomena seen in heavy bedded sandstones are found in these fragmental deposits.

ONONDAGA REEF OF WILLIAMSVILLE, NEW YORK

The Jones lime quarries of Williamsville, New York, are opened on the flanks of a coral reef, in the inface of the Onondaga cuesta. The reef itself is exposed only in the floor of the old quarry on the western flank of the dome. Here in the south wall the beds have a general dip of from 5 to 10 degrees westward, and a similar one, in the east and west walls, to the north. These dips indicate that the quarry is situated on the northwest quarter of the dome. In the new, or eastern, of the two quarries the dip is eastward and northward, while a southward dip is also found in one portion of the quarry. This one, therefore, is opened in portions of both the northeast and the southeast quarters of the dome. It is also opened at a greater distance from the center of the reef, no portion of this being actually exposed in the quarry. The north and south extending walls of the quarries farthest removed from the reef show horizontal bedding, because the dip in these is at right angles to the wall—that is, either east or west; while the walls nearest the reef show the north and south dips. Corals are most abundant in the western portion of the eastern, and in the eastern portion of the western quarry—that is, nearest to the reef in each case; while away from the reef the rock becomes a regularly bedded consolidated coral and crinoid sand. The floor of the western quarry near the reef consists of a mass of cemented coral heads, among which Favosites, Diphyphyllum, Syringopora, Cyathophyllum, and Cystiphyllum predominate. Crinoid stems

are also numerous, and generally more or less dissociated into their component joints. In the center of this old quarry is a smaller subsidiary reef composed of the same fossils, notably of Cystiphyllum. It consists of an unstratified mass of cemented corals, mostly in the position of growth, while the stratified beds dip away from it in all directions. The smaller reef, then, bears the same relation to the larger one that the monticule of a volcano bears to the main cone.

The corals of the bedded limestone in the neighborhood of the reef are fragmental and may lie in almost any position. They indicate considerable wave activity around the margins of the reef. Within the reef brachiopods are less abundant than on its margin, while in quarries opened at some distance from the reef brachiopods are abundant between the strata of fragmental limestone. As may be surmised, the absence of bedding and jointage within the reef proper makes this portion of the rock difficult to quarry, since it can be broken only by blasting. Therefore we find that the reef is generally avoided in quarrying operations, which is true even of the monticuloid subsidiary reef before mentioned.

*SILURIC REEFS OF SOUTHEASTERN WISCONSIN**

Reef structure is of common occurrence in the Siluric (Niagaran) limestones of southeastern Wisconsin. One of the best known examples is the old Shoonmaker quarry, near Wauwatosa. This has been fully described by Chamberlin,† who recognized the reef character of the main rock mass of the quarry. The quarry was opened in a mound or hillock which undoubtedly owed its preservation to the hard character of the reef mass. At the time of my visit, however, it had been abandoned for a long time, and the walls had become more or less weathered and overgrown, while the deeper portion was filled with water. The same reef is exposed in the eastern part of the quarry, but there are smaller reef-like mounds which may have been subsidiary reefs, or may be merely parts of the larger one. No bedding is visible in the reef portions, which appear to consist mainly of stromatoporoids. These, however, are recognizable, as a rule, only on the weathered surfaces, the general aspect of the fresh face being that of extreme massiveness of the rock, with a total absence of stratification. Around the reef, however, the rock is bedded and granular, and it may be seen in many places dipping away from the central reef portion. The highest dips which I

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* In the study of the reefs around Milwaukee I enjoyed the guidance and coöperation of Dr E. C. Case, of the State Normal school, and in Cedarburg my studies were greatly aided by Mr Arthur Boerner and the Reverend Charles Lange, of that town. To these friends my sincere thanks are tendered.

† Geology of Wisconsin, vol. ii, 1877, p. 364.

observed were 28 degrees, decreasing rapidly to 18 degrees; but Chamberlin mentions a dip of 54 degrees close to the reef, observed while the face was well exposed in quarrying. Other dips mentioned by Chamberlin are 30, 31, and 34 degrees, beside those of lower angle. Chamberlin also mentions the increase in thickness of the sedimentary layers toward the reef, with which they finally merge.

Among the other reefs mentioned by Chamberlin is that of Moody's quarry, in the fourth ward of the city of Milwaukee, and in the bluff facing the Menomonee river. This old quarry (Distillery quarry) is at the foot of Twenty-ninth street. The reef is of the same type as that of the Wauwatosa quarry, but the dips are very steep, averaging 40 degrees toward east and west and 20 degrees or more southward. A third reef occurs in the grounds of the National Military asylum. This I have not seen, but, according to Chamberlin, it forms a triangle with the other two mentioned. In all cases the reefs constitute mounds, owing to their superior compactness, which permitted resistance to erosion. The older quarries were generally opened in these mounds. Within the triangle made by these three mounds the great limestone quarries of this region are now opened up. Here we find only even bedded limestone, consisting of coral and crinoid debris and but sparingly fossiliferous. Regarding the fauna of these limestones Chamberlin says:*

" . . . Upon the reefs there swarmed a vast variety of life; . . . upon certain banks or shoal areas there was also great abundance and variety, among which the crinoid family attained unusual prominence; . . . over areas of submarine sand flats there either was little life present or, from the porous nature of the rock, it has been illy preserved, and . . . over the deep areas that deposited fine calcareous mud the gigantic Cephalopods held sway."

In the vicinity of Cedarburg several quarries show reef characters. Groth's quarry, near the railroad station, is opened in the flanks of a reef which forms a hill, and is shown in the eastern wall of the older, abandoned portion of the quarry. Fossils are numerous in this portion, consisting chiefly of corals, though mollusk shells are also common. The bedding is obsolete here, while stylolite structure is commonly seen. In the western part of the old portion of the quarry bedding is well shown, the strata dipping west and south. Correspondingly, fossils are scarce. The part of the reef exposed is about 30 or 40 feet in thickness, while the length from north to south is perhaps 300 feet. Dolomitization has gone on to a considerable extent, and in many of the bedded strata the corals have been dissolved out. As a result, cavities, either lined with crystals or empty, abound, these usually marking the former position of a stromatoporoid or other coral. In the new portion of the

* Geology of Wisconsin, vol. ii, p. 369.

quarry the rocks are all composed of coral, shell, or crinoid sand, and are locally known as sandstones. Fossils are rare, those found being chiefly brachiopods or crinoid fragments, with an occasional cephalopod shell. The succession of bedded strata is as follows:

3. Porous vermicular dolomite, brittle and with stratification poorly developed, full of cavities of dissolved corals	about	20 feet
2. Hard white granular lime rock	about	8 feet
1. Soft friable brown lime sandstone		10 feet
Total	about	38 feet

Anschütz's quarry, in Cedarburg, is opened in a hill, near the center of which, south of the quarry, occurs a reef, as indicated by the nature and dip of the strata. The dip is 10 degrees northeastward. The limestones of this quarry are all well bedded and uniform, sugary in texture and with few fossils. Those found are chiefly brachiopods. The rock here has the structure of a sandstone, by which name it is familiarly known. Other quarries and natural exposures on the Milwaukee river near Grafton show similar bedded limestones, but no other exposures of reefs were found.

SILURIC CORAL REEFS OF GOTLAND

Dr Carl Wiman has described * the characteristics of a certain type of "Klintar" of the northwest coast of the island of Gotland as representing reef masses of the Siluric formations of that region. These compact reef masses have resisted erosion more readily than the connecting beds of stratified material, and hence they form a succession of prominent headlands where they have come within the zone of wave activity on that coast. The main mass of the reefs is unstratified, or at best the bedding is but slightly developed. In form they are lens-like, and they consist chiefly of masses of coral, stromatoporoids, and bryozoa, which have grown in situ, together with calcareous algæ. Between these, remains of brachiopods and crinoids are abundant. On the flanks of the reefs are found conglomerates and breccias of coral masses, such as Halysites and Cystiphyllum, and crinoidal remains. The coral heads of the margin of the reef are often overturned, while farther away they are most generally fragmentary. Along the margin of the reef, furthermore, there is a periodic overlapping of the fragmental and organic rock, as has been noted for the reefs previously described. Even within the reefs occur small wedges of sedimentary beds, while beds not infrequently suddenly thicken on reaching the reef, a feature already noted, as found by Chamberlin in the Siluric reefs of Wisconsin. Similarly, we meet

* Uber Silurische Korallenriffe in Gotland. Bull. Geol. Instit. of Upsala, vol. iii, 1897, pt. 2.

with a wedging out of marginal rims of the reef between the sedimentary beds.

DEVONIC AND CARBONIC REEFS OF BELGIUM

Dupont* has described the reefs in the Devonic limestones of Belgium. The reefs have at first impression the appearance of amorphous limestone, passing into more or less saccharoidal rock. On weathered faces a somewhat brecciated structure appears, together with numerous outlines of corals or sponges, slightly put in relief by a granular lime which is more soluble. The mass consists of a vast number of skeletons of coelenterates which have been profoundly altered, as evidenced by microscopic examination. It is generally impossible to separate the lamina of these masses with the hammer, but in a few cases where perfect separation has been possible the true character of the remains was determined. They are chiefly stromatoporoids, which make up a large part of the reef, though other organisms are not uncommon.

The stromatoporoids show their characteristic structure only on weathered surfaces, while on fresh fracture the rock is compact, often with glassy fracture, and full of cavities, and without any evidence of organic remains. No stratification is visible in this mass, but is well marked in the flanking beds of clastic limestone. Beside the stromatoporoids (Stromataclis and Pachystroma) the reef formers include Favosites, Alveolites, and more rarely Cyathophylloids ; but *Cyathophyllum cæspitosum* occurs on the margin of some reefs in crowded heads of 1.50 to 2 meters in diameter.

The Carbonic "Calcaire de Waulsert" is described by Dupont † as composed of an agglomeration of *Stromataclis bulbaceous* and *Ptylostroma fibrosa.* To the surfaces of these adhere numerous fronds of Fenestella. Corals play only a small part in these reefs, including merely *Amplexus coralloides* and a few other rare types. Small massive heaps or islets of these reefs are scattered through the formation. Around the reefs, and entangled with them, occur limestones of diverse character, but chiefly marked by the clearness of their stratification. Among these limestones we can distinguish two distinct varieties, the crinoidal and the amorphous. The crinoidal rock, formed by the dissociation of the joints of crinoid columns, occurs in channels in the reefs.

Summary of Characters of Paleozoic Coral Reefs

We may sum up the characters of the reefs mentioned as follows: In

* E. Dupont: Sur l'origine des calcaires devoniens de la Belgique; Bulletin de l'Académie Royale de Belgique, ser. 3, T. 2, 1881, pp. 264–280.

† E. Dupont: Sur les origines du calcaire carbonifère de la Belgique; Bulletin de l'Académie Royale de Belgique, ser. 3, T. 5, 1883, pp. 211–229.

general aspect they are roughly lens-shaped to dome-shaped masses of calcareous material, devoid of regular structure, without any, or with only faintly developed stratification, and composed of corals, hydro-corallines, sponges, bryozoa, calcareous algæ, and other reef-building organisms, which grew practically where they are now found. With these, but more abundantly on the flanks of the reef, are found the remains of innumerable crinoids, brachiopods, and other attached organisms; while remains of vagrant types, such as mollusks and crustacea, occur in every part of the reef, frequently in great profusion. On its flanks, where the reef was constantly attacked by the waves, large masses of broken coral occur, which are more or less worn and embedded in the coral and crinoid sand which forms the chief enclosing mass of the reef. This sand, which is of varying degree of fineness, is perfectly stratified, the beds dipping away from the reef at high angles in all directions, but soon falling to a low angle of dip. Around the reef occur interstratifications of the bedded sand and the organic masses, the latter not infrequently extending far out over the bedded rock, between which and the next overlying bed they form a dividing film. Away from the reef we often find rock of the finest lime mud, which settled in the quiet and deep water at a distance from the source of the material.

Comparison with modern Coral Reefs

A comparison of these ancient reefs or knolls of coral rock with those of modern time shows close analogy. In modern reefs the clusters of growing corals "are scattered like tufts of vegetation in a sandy plain,"* and surrounding and connecting the lens-shaped reefs is the coral sand, which is often entirely without recognizable organic remains. In the neighborhood of the growing reef the rock is often a breccia or conglomerate.

Except where a reef rises from great oceanic depths, the slopes are frequently much below 10 degrees. This is particularly the case in the Bermudas, where the slopes are very low. Thus the following are given for Hamilton: †

Westward, for the first 8.9 kilometers, the slope averages 21 degrees 50 minutes; for the next 11 kilometers it averages 1 degree 20 minutes, and for the next 36 kilometers it averages 2 degrees 27 minutes. On the same island the slope to south-southwest is 3 degrees 22 minutes for the first 20.5 kilometers, 3 degrees 8 minutes for the next 5.5 kilometers, 3 degrees 55 minutes for the next 8.0 kilometers, and 4 degrees 9 minutes

* J. D. Dana: Corals and Coral Islands, p. 174.

† Dietrich, quoted by Walther.

for the next 26.7 kilometers. Of forty-one slopes determined on the Bahama islands, the lowest is 0 degree, the highest 26 degrees 18 minutes. Seventy-five per cent of the slopes are below 10 degrees, while one-third of the entire number of determined slopes fall below 5 degrees.

On the Keeling islands, on the other hand, only a few slopes below 10 degrees are recorded by Dietrich. Nearly half of the number lie between 30 degrees and 43 degrees, one being as high as 63 degrees 21 minutes. In the section of one of these islands given by Darwin the slope is at first a very gentle one, plunging at a distance from shore only, at an angle of 45 degrees. On these islands Darwin also found that below 20 fathoms depth the material of the bottom was coral sand, while above 12 fathoms the bottom was free from sand. The sand brought up from a depth of 200 to 300 fathoms was mainly of finely triturated fragments, while shell fragments were rare. Along the outer margin of the reefs breccias and conglomerates of coral fragments are found. These are firmly cemented even in the growing reef, so that Darwin found difficulty in chopping off fragments even with a chisel.

Origin of the Coral Sand

The production of the coral sand is partly due to the direct activities of animals which feed on the calcareous organisms and partly to the activities of the waves themselves. Fish feeding on living corals were found by Darwin to have their intestines distended by small pieces of coral and finely ground calcareous matter. This must pass daily from them as the finest sediment. Worms, mollusks, crustacea, and holothurians also grind up rock. These organisms are numerous on every modern coral reef, where they find a rich feeding ground. The most efficient among them are probably the crustacea, and these are generally credited with the production of most of the coral sand.

In the Paleozoic reefs, however, the crustacea probably played a minor part in the reduction of coral masses to sand and fine silt. While trilobites may have been active in this respect to some extent, they can not be regarded as possessing even in a fair measure the efficiency of the modern decapods. Moreover, trilobite remains are not always common in these reefs. While, therefore, a part of the production of the coral sand and mud is undoubtedly due to these and to the other types of animals mentioned, the greater part of the detrital material could not have been produced by them. A very important factor, and the one believed by Wiman to have caused the production of most of the lime sand of the Siluric beds of Gotland, is the natural tendency of echinoderm skeletons to become dissociated into their component plates on the death

of the animal. This is particularly true of crinoid stems and calices, the former by their length constituting an important source of calcite fragments. Thus are produced the crinoidal limestones which play such a great role among the Paleozoic sediments. The component particles of these crinoidal limestones vary greatly in size in different beds, but are usually quite uniform in the same bed. The average size of the grain will of course be determined by the size of the stem joints of the predominating species of crinoid. These crinoidal limestones are often as well developed where no reefs are found as they are in the neighborhood of the reefs, where they are often of secondary importance. Thus in the rocks surrounding some of the Devonic coral reefs mentioned crinoidal limestones are not at all common, whereas in many of the coarser beds the grain is much finer than the size of the smallest plate of a crinoid stem, while others are composed of impalpable lime mud. It is mechanically ground up coral rock, ground often into an impalpable lime mud, that constitutes these limestones.

It appears, then, from our present knowledge that the Paleozoic reef corals were ground up chiefly by the action of the waves. Walther* finds this to be the case in modern reefs, where rock masses, either foreign or broken from the reef, are rolled about over the corals and shell accumulations, grinding them into sand and flour, but in the absence of such blocks he finds that the chief reef destroyers are the fish and crustacea, together with numerous other organisms which assist in a minor way in destroying the calcareous structures. While foreign blocks are unknown in the Paleozoic reefs, a very effective tool for grinding up shells and the smaller corals was present in the huge coral heads themselves. When a Stromatopora head 4 to 8 feet in diameter was rolled about on the margin of the reef by the waves much grinding up of minor calcareous structures must have resulted. The heads of Favosites and of Acervularia, which, with the stromatoporoids, constitute the chief reef builders, were likewise effective destroyers when rolled about by the waves; and that they were thus rolled about is shown by the worn and broken character of all such masses near the reef margin, and the fact that heads many feet in diameter are found overturned or lying on their sides. It is probable that the crinoidal fragments in the neighborhood of the reef were thus ground up into sand and flour, and so converted into clastic sediment.

The fine lime flour, the most impalpable product of the erosion of the reef, would, of course, be deposited in the quieter water beyond the reef. Around modern coral reefs the water after a storm is milky for great

* Einleitung in die Geologie, p. 926.

distances, owing to the presence in suspension of this lime-rock flour. Agassiz has noticed this fine sediment in suspension at a distance of 12 to 20 kilometers from the reef. After a prolonged storm, 4 to 5 centimeters of coral mud were laid down between two tides.*

Bryozoa Reefs

Another type of reef common in some of the Paleozoic rocks has attracted considerable attention. These are lens-shaped masses of compact argillaceous limestone embedded in stratified limestones or shales. They are found in the Siluric of western New York, and have been described by Ringueberg,† Clarke,‡ Grabau,§ and Sarle.‖ They consist of a structureless mass of compact argillaceous limestone, in which organic remains are commonly abundant. These lenses, as pointed out by Sarle, are Bryozoa reefs, around and on which organisms of varying types found a congenial feeding ground. The fine calcareous sand caught and held by the bryozoan fronds helped to build up the reef rock and buried the remains of the organisms feeding on these reefs. Some of the "Klintar" of the coast of Gotland appears to be of this type of reef.

Classification of Reef Limestones

GENESIS OF THE LIMESTONES

When we now consider the genesis of the limestones which enter into the composition of a coral reef, we notice at once that a division into two groups is possible—the organic and the clastic. The organically formed limestone is seen in the reef itself, where the coral masses remain more or less in the position in which they grew. On the margins of the reef we have the broken coral breccia and conglomerate, while farther away we have the stratified coral sand rock. Finally, in the quieter places, is formed the coral silt or coral flour rock. These three types of clastic limestones may be found in the neighborhood of nearly every coral reef, and they generally form the economically more important portion of the deposit, since they are well stratified and readily quarried for building purposes or for lime. This is particularly the case with the coral and shell sand limestones and those composed of lime mud.

*A. Agassiz: Three Cruises of the *Blake*, vol. i, p. 84; quoted by Walther, p. 929.

†Am. Naturalist, September, 1882, p. 711.

‡Report of State Paleontologist for 1899.

§Guide to Geology and Paleontology of Niagara Falls, 1901, pp. 99-102.

‖Clifton J. Sarle: Reef structures in Clinton and Niagara strata of western New York. Am. Geologist, November, 1901, pp. 282-299, pl. 27-31.

For the clastic limestones here discussed the names *calcirudite*, *calcarenite*, and *calcilutite* are proposed.* They may be defined as follows:

CALCIRUDITE

(Etymology: calx = lime + rudus = rubble)

A limestone or dolomite composed of broken or worn fragments of coral or shells or of limestone fragments, the interstices filled with lime sand or mud and with a lime cement. It corresponds to psephite among the siliceous rocks.

Some of the varieties of calcirudite are:

1. Coral breccia.
2. Coral conglomerate.
3. Shell breccia.
4. Shell conglomerate.
5. Limestone breccia.
6. Limestone conglomerate.

The last two well known varieties must be included under the term calcirudite, even though they are made up of old sedimentary limestones which have been broken and recemented.

Stratification is more or less marked in calcirudites, as it is in other coarsely fragmental rocks. On the one hand they grade into the unworn organic deposits or into the solid limestone beds, and on the other into the members of the next division.

CALCARENITE

(Etymology: calx = lime + arena = sand)

A limestone or dolomite composed of coral or shell sand or of lime sand derived from the erosion of older limestones. In structure it resembles psammites or siliceous sandstones, being generally known by the term sandstone. Stratification is well marked, and the rock not infrequently shows cross-bedding structure, as noted among the dolomitic calcarenites of the Niagara gorge.† Ripple marks have also been noted in some impure fine grained calcarenites of the Traverse group of Michigan.‡ Calcarenites constitute the main mass of the limestones of the Traverse group of Michigan, of the Onondaga of southeastern Michigan and western New York, and of the Niagaran beds of southeastern Wisconsin. Much of the Lockport limestone of western New York is a calcarenite, and, in fact, so far as my observations go, a large proportion of

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*I am indebted to Professor Wm. North Rice for suggestions regarding the orthography of these terms.

†A. W. Grabau: Guide to Geol. and Pal. of Niagara Falls, pp. 107, 108.

‡Grabau: Ann. Rep. Geol. Surv. Mich., 1901, p. 209.

the bedded Paleozoic limestones must be referred to this type of rock. It is not always readily distinguishable from crinoidal limestone, which must be considered an organic and not a clastic rock. In fact, these two types of rock often grade one into the other.

Among the varieties of calcarenite may be mentioned:

1. Coral and shell sand rock—marine.
2. Coral and shell sand rock—æolian (as in the case of the Bermudas).
3. Limestone sand rock, practically indistinguishable from number 1.

Calcarenites are not infrequently wholly barren of organic remains, as is the case with ordinary sandstones. Some typical calcarenites of the Traverse group of Alpena, Michigan, have analyzed over 99 per cent $CaCo_3$. Others approach in composition pure dolomites. A perfect gradation exists between this and the next group.

CALCILUTITE

(Etymology: calx = lime + lutum = mud)

A limestone or dolomite made up of rock flour, the composition of which is typically non-siliceous, though many calcilutites have an intermixture of clayey material. They correspond to the pelites among the siliceous rocks. The purest calcilutites, with a composition of 96 per cent or over of $CaCo_3$, or of $CaCo_3$ plus varying amounts of $MgCo_3$, have generally a compact structure with a conchoidal fracture. They may be thin bedded or heavy bedded, in the former case not infrequently showing ripple marks, as has been observed on an extensive scale in Upper Siluric calcilutites on the Beaver islands, lake Michigan. The rock here analyzed nearly pure calcium and magnesium carbonates.*

Two chief varieties of calcilutite may be considered, namely: Rock composed of the lime mud resulting from the trituration of organic deposits, such as coral reefs or shell or crinoid beds, and rock made of the consolidated mud resulting from the erosion of older limestones. The latter type appears to be exemplified by the dolomitic calcilutites of the Upper Monroe beds of Michigan, including those of the Beaver islands already mentioned. As organic remains are rare in this entire formation, it must be assumed that the material of these limestones was derived from the erosion of the underlying Niagara dolomites, unless, indeed, we assume, as has been done, that they are chemical sediments. Calcilutites of a less pure character are found in the water limes of New York, and probably in those of New Jersey and Pennsylvania. Unless these are considered of chemical origin, the source of the material com-

* Reference to unpublished notes on the Michigan rocks is made by permission of the state geologist, Dr A. C. Lane.

posing them must be preexisting limestone beds. Their fine stratification, which has procured for many of them the name of ribbon limestones, seems to point clearly to normal sedimentation of detrital material as their source. These limestones all contain a considerable amount of clay intimately mixed with the lime, which makes them fit for a natural cement rock. Fossils were well preserved in these muds, and their paucity must be considered as due to the scarcity of animal life in the seas where these deposits were accumulated.

It will be noticed that in each of the three groups we have limestones which were derived directly from the original organic deposits, or chemic precipitates ; and those which were secondarily derived from older limestones, these in turn being generally of clastic origin. The first may be considered as clastic limestones (calcirudites, calcarenites, or calcilutites) of the first generation, the others of the $n^{th} + 1$ generation, in which n may be the first or any later generation.

Suggested Classification of Limestones

By the foregoing considerations we are led to divide limestones, as a whole, into two main classes, the non-clastic and the clastic. As Walther has well maintained,* the metamorphic phase of these limestones should not be considered a primary division.

I. Under the non-clastic limestones we have:

- *A*. Chemically deposited limestones, which include:
  - (1) Original precipitates in the sea or lake, including chemically formed oolites.
  - (2) Local precipitates from redissolved limestones. Among these are:
    - (*a*) Cave deposits—that is, stalactites and stalagmites.
    - (*b*) Travertine or calcareous tufa.
- *B*. Organically formed limestones, which include:
  - (3) Unassorted or non-stratified organic limestones, such as reef rock, made of corals, bryozoa, hydrocorallines, calcareous algæ, etcetera.
  - (4) Assorted or stratified organic limestones, such as—
    - (*c*) Shell beds, composed of shells of mollusks, brachiopods, echinoderms, and the larger foraminifera—that is, Fusulina, Nummulites, etcetera. These grade imperceptibly into the clastic shell conglomerates and breccias.
    - (*d*) Shell ooze limestones, including chalk, globigerina ooze, pteropod ooze, entomostraca ooze, etcetera, and the limestones resulting from their consolidation.

* Johannes Walther: Versuch einer Classification der Gesteine auf Grund der vergleichenden Lithogenie. Congrès Géologique International Compte rendu de la VIIme. Session. St. Petersbourg, 1897, 3me Partie, pp. 9-25.

(*e*) Crinoidal limestones, composed chiefly of the stem joints of crinoids which become dissociated on the death of the animal.

(*f*) Oolites and other stratified deposits due to lime-secreting algæ which are not attached. Here belongs the oolite of Great Salt lake.

II. Under the clastic limestones we have, as already noted:

C. Calcirudite, comprising coarsely fragmental or "rudaceous" rocks derived:

(5) From contemporaneous organic limestones, including:

(*g*) Coral breccia.

(*h*) Coral conglomerate.

(*i*) Shell breccia.

(*j*) Shell conglomerate, or

(6) From older limestones, including:

(*k*) Limestone breccia.

(*l*) Limestone conglomerate.

D. Calcarenite, comprising moderately fine or "arenaceous" rocks, derived:

(7) From contemporaneous organic limestones, including:

(*m*) Coral and shell-sand rock, aqueous, generally marine, and

(*n*) Æolian coral and shell sand rock.

(8) From older limestones, comprising:

(*o*) Limestone sand rock, probably indistinguishable from (*m*), but recognizable by the absence or scarcity of organic remains in the formation in which it occurs.

E. Calcilutite, comprising fine grained, compact, or "lutaceous" rocks, formed of rock flour, generally with conchoidal fracture, and derived:

(9) From contemporaneous organic limestones ground into flour, comprising:

(*p*) Lime-flour rocks, from coral reefs, shell heaps, etcetera, and

(10) From older limestones, comprising:

(*q*) Lime-mud rocks, generally well stratified and including pure carbonate rocks and water limes in which there is an argillaceous admixture.

Through metamorphism all the above rocks will be changed to marble.

The classification here given is intended merely as a suggestion. I believe that the genetic method will eventually be followed in the classification of sedimentary rocks, as Walther has so strongly advocated.

With refinement in classification it will probably be necessary to create many new distinctive terms of limited meaning, so that the old time-honored names of limestones, sandstones, slates, shales, etcetera, will be used only in more general discussions.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 14, PP. 353-368, PLS. 49-53 SEPTEMBER 12, 1903

CONCRETIONS AND THEIR GEOLOGICAL EFFECTS

BY J. E. TODD

(Read before the Society January 1, 1903)

CONTENTS

INTRODUCTION

Some over thirty years ago the writer's attention was turned to the peculiar cracked concretions abounding in loess, which are known as loess kindchen. Not satisfied with current explanations of their origin and history, he has ever since improved opportunities to note and collect concretions, which abound in vast numbers and of numerous types in the Mesozoic and Cenozoic formations of the west. This paper presents some of the more prominent conclusions for consideration and criticism. Some well known facts are briefly recapitulated for the proper setting forth of the more novel conclusions.

It should be stated at the outset that the author disclaims intimate acquaintance with the chemical aspects of the subject. His data are

mainly observational, not experimental, and his discussion physical and not to any considerable degree chemical. Literature on the subject is meager. Some writers comment on the subject as quite obscure.*

Concretions Defined

Concretions are stones that grow, or, in other words, are nodular growths of various minerals sparsely distributed through the country rock. They vary greatly in size, shape, composition, distribution, and method of growth.

They should be distinguished from secretions, which may sometimes resemble them in form and structure. Such growths are formed in cavities, and the outer layers are the older instead of the younger, as is commonly the case in concretions. Geodes may be considered as imperfectly filled secretions. Though often externally resembling concretions they differ from most of the latter by being hollow, and from those concretions which are cracked within, by having a simple cavity bounded by a shell of nearly equal thickness throughout.

Concretions differ from stalactites, either pendant or coralloidal, which are formed in the former case by trickling water, and in the latter case by oozing water; they also differ from stalagmites which result from dropping water; and from other forms of cave deposits, as these are all found with free surfaces and not embedded, as is always the case with concretions. Moreover, though all grow mainly by additions to the outside, like concretions, and though portions of them may resemble concretions in form, yet they are always attached by a base to country rock, which is never true of concretions.

Concretions and Crystals

Crystals are the normal form which minerals take when solidifying from solution or fusion without the interference of surrounding material or contact with each other. Concretions result when the embedding rock prevents the orderly arrangement of the molecules, though they may still cohere in an irregular way. Evidence for this conception is found in the numerous gradations observed between the typical extreme cases. This is shown by numbers 8–10 and 17–21, plate 49, and numbers 5 and 7, plate 50.

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* Furthermore, the discussion is limited to structures formed from aqueous solution and does not treat to any considerable extent of those formed through the medium of liquids of fusion. Quite possibly similar physical relations may occur in both, and consequently sometimes processes and structures appear in the latter case similar to those we describe in aqueous deposits. Lithophysæ and other concretionary structures found in igneous rocks would seem to corroborate such a view, but we have not had opportunity to study such forms.

From what has been said the inference is easy that crystals form where the collection of molecules takes place in an open space, or a space occupied only by liquids, while concretions grow embedded in the country rock. This is true in general, but there are some exceptions. Crystals like garnet, tourmaline, etc., form apparently in rock excluding the surrounding grains, while calcite frequently forms crystals including grains of sand naturally lying within their limits.

The force conceived to bring together molecules into either crystals or concretions is a form of molecular attraction, influenced perhaps, sometimes, by electrical relations. This attraction withdraws molecules from the mother liquor in the immediate vicinity of the crystal and builds them into its structure. This impoverishes the solution in contact, and consequently diffusion takes place from the saturated solution farther away to enrich it. As these processes continue, quasi-currents of molecules similar in nature to those of the crystal converge toward it from all directions and from an indefinite distance. It is not necessary to postulate motion of the liquid which acts as a vehicle, though motion of such medium may sometimes accelerate or otherwise influence the growth of both crystals and concretions. The impoverishing of the surrounding country rock in the vicinity of concretions is often conspicuously indicated by a difference of color.

Size

Concretions vary greatly in size, some being microscopic and others attaining several yards in diameter. As in the case of crystals, the size of concretions is probably inversely as the rapidity of their formation. Another limiting factor may be the strength of solution from which they form.

Shape

When concretions form in a massive deposit where the circulation is equal in all directions, the usual shape is globular. This is often beautifully exhibited in sandstone. It has been observed particularly in those of the Fox hills and Laramie formations. The latter case is recorded in the names of the Cannon Ball river and the Pomme Blanche hills of North Dakota. Such are found also in the marls and loams of the Miocene and Pleistocene. When formed in shaly formations, as noted long ago, the shape is usually more or less lenticular, because accumulation goes on more rapidly in the plane of stratification than at right angles to it. If shales are very impervious the concretions may be disk-like, as in figure 22 *d*, plate 49, and figure 3, plate 50, or even sometimes

ring-like. When these various forms are near enough to coalesce, very complex and often surprisingly imitative forms appear—tubers, riveted plate, and grotesque imitations of fruits, roots, parts of animals, or various utensils. These are frequently collected in amateur museums. When large they may be looked upon as of almost miraculous origin and become objects of superstition.

In loams, especially in connection with root marks, as explained later, concretions are often vertically elongated, so as to resemble tubers and fusiform roots. Again, some concretions, for some reason not yet satisfactorily explained, are very much elongated horizontally. In the Laramie formation they attain size and shape fitly described as log-like (see plate 51, figure 1). They have been found over 100 feet in length, counting the divisions separated by cross-joints. The detached sections not infrequently closely resemble in shape, size, and color saw-logs stripped of their bark. It has been suggested that they have formed around organic matter collected in furrows on the beaches of lakes.* This opinion is strengthened by their often occurring parallel with one another, and sometimes so near as to coalesce, as in plate 51, figure 2. Moreover, those on about the same level have been observed to lie in systems, extending for many rods, or even miles, perhaps, in broadly sinuous lines, like a lake shore.

Location

Concretions, like crystals, seem to owe their location to predetermining circumstances. In the case of the latter a particle of similar substance accidentally present seems to act as a starting point or nucleus. A particle of precipitating agent may also act in a similar way. Bones, leaves, shells, etcetera, are found embedded by the concretions which have formed around them; but where no such nuclei are present the precipitating mineral tends to concentrate itself at nearly equidistant intervals. If the precipitating influence is at high temperature and progressing rapidly, we may expect these centers will be nearer together and the resulting concretions smaller.

The foregoing remarks apply to spaces fully submerged in ground water or far removed from the surface of ground water. It is probable, however, as will appear from consideration given in a subsequent section, that the surface of the ground water, or water-table, is preeminently a zone of concretionary growths. There the various precipitating influences are especially active, and by the fluctuations of the surface of the ground water this action is intermittent, which fact sometimes increases

*J. E. Todd: American Geologist, vol. xvii, 1896, p. 347.

its efficiency, as will be seen later. Concretions also form around openings, particularly around root marks or tubules, by which more direct connection is kept open with the outer atmosphere. This is particularly true of what we have described further on as incretions.

Chemical Composition and Conditions of Formation

As already hinted, concretions are rarely pure or composed of any one mineral, but almost always include more or less of the rocks in which they grow. Almost any soluble mineral may take concretionary form if only evaporation or cooling gradually reduces the solution below the point of saturation. Of course, only those which are nearly or quite insoluble under ordinary circumstances will form permanent concretions. The more common concretions are therefore those formed by chemical reactions which produce insoluble minerals from soluble.

Doubtless calcareous concretions—that is, those composed of calcium carbonate—are the most abundant, for carbonate of lime is everywhere, and carbonic acid, its solvent, is quite as common. Moreover, the conditions are frequent for its evaporation and the formation of carbonate of lime, which is nearly insoluble in common waters.

In quite a similar way carbonate of iron, or siderite, forms concretions of clay ironstone, which are very common in certain strata. Another quite common concretionary mineral is iron pyrites. It is hard as steel, and its concretions of much size are formidable hindrances to the well-driller. Fortunately they are commonly thin and brittle. Ferric sulphate reduced by carbon in organic compounds becomes FeS_2, and possibly also ferrous carbonate acted upon by hydrogen sulphide produces the same compound.

Silica even may be gathered in concretions from an alkaline solution or from a solution of alkaline silicate through reaction with carbonate of lime. Several of these processes are not fully understood, and the above statements are not to be taken as results of careful experimentation, but as generally expressed probable reactions, strengthened in some cases by corroborating observations.

Another cause of precipitation quite different from most of the others is the easy combination of oxygen with a ferrous compound, like ferrous carbonate and ferrous sulphate, and probably also organic salts, by which an insoluble ferric hydroxide is formed. This is particularly influential in forming ferric concretions of the incretion and excretion types.

The following is a table of chemical reactions probably producing concretions:

Solutions of—	*By—*	*Become solid—*
$CaCO_3$, H_2CO_3	Evaporation of CO_2	$CaCO_3$ (calcite).
$FeCO_3$, H_2CO_3	" " CO_2	$FeCO_3$ (siderite).
" "	Action of H_2S	FeS_2 (pyrite).
" "	" " $CaCO_3$	Fe_2O_3, $3H_2O$ (limonite).
" "	" " oxygen	" " "
$FeSO_4$	" " "	" " "
"	" " organic matter	FeS_2
Na_2SiO_3	" " $CaCO_3$, or $CaSO_4$	SiO_2 (quartz).
Any substance	Drying or cooling	The same.

Methods of Growth

ACCRETIONS

The common conception of the growth of a concretion, as is perhaps suggested by the name, is that particles are gathered together toward the center so as to produce growth regularly and steadily from the center outward. Such may be aptly called an *accretion*. Such accretions, from the nature of the case, will be solid and include or enmesh particles of the rock in which they form without any considerable disturbance of them. It is conceivable that the molecular attraction between the molecules of the concrescent minerals may be so strong as to exclude foreign particles to some extent, but evidence of such action has not been often observed. That carbonate of lime is not likely to do so with common sand, seems attested by the occasional formation of regular calcite crystals with true angles and planes in sand, which include the sand grains lying within the space of the crystal without any trace of exclusion. As crystal growth is without doubt by simple accretion, it follows easily that calcareous accretions will not exclude sand, even if they may some other foreign particles, and it seems probable that other concretion forming minerals act in a similar way in similar circumstances.

Simple accretions in stratified material preserve the stratification in their substance. Accretions may also have a radiate structure, which may be due to the development of a modified crystalline structure. They may probably also show rhythmical or concentrically banded structure as in figure 12, plate 49. This is not certainly known but probable. It may be due to conditions corresponding to those which form specter and concentrically stratified crystals—that is, to intermittent periods of deposisition with possible-counter influences between, or to the intermittent deposition of impurities or of some coloring matter.

While it can not be questioned that they are normally solid, it is conceivable that sometimes a wet mass of calcium hydrate or of calcareous

clay may act as a nucleus, and after the formation of a more rigid shell that subsequent shrinking by drying may produce a cracked interior, as Professor Dana and other writers have stated. The writer, after considerable study and observation, is not aware of any clear proof of such a case. In all concretions observed the cracked portion has not been of such a character, but of similar composition to that of the rest of the concretion.

INTERCRETIONS

On the contrary, from a study of such growths we have been led to quite a different explanation for those showing a cracked interior. Instead of the interior shrinking after the outside has become rigid, on the contrary the outside or outer portion has expanded and become too large for the interior, and it has done so with sufficient force to wrench apart the interior. Moreover, this has been a gradual process, the growing zone passing gradually outward by contemporaneous accretion. The cracks starting first in the central portion gradually follow the growing zone outward. This process is theoretically shown in figures 3*a*–*e*, plate 49. To simplify the case, a globular form is assumed, but a lenticular shape, similar to figure 4, is more common in the Cretaceous shale of Dakota, and vertically elongated ones or rudely globular are more common in loess, as in figures 5 and 22*a*. In the Benton and Pierre clays they grow to a size of several feet, sometimes a rod or more in extent. They are cracked into polygonal blocks 3 or 4 inches across. The evidence in favor of the conclusion stated above may be given as follows:

1. The cracking can not be due to drying, because (*a*) the material is not clayey, but usually contains much sand, and is not distinguishable from the outer portion of the concretion; (*b*) because the concretions are sometimes found by well diggers to be filled with water, and from this fact, as well as from their shape, they are called "jugs." Moreover, the crevices are often lined with crystals or filled with crystalline matter. In the latter case the structure is known as a septarium. Such facts show that the interior was saturated with water probably during all the time of its formation. If the shrinkage was due to desiccation, why should not the material when wet again recover its former bulk and the cracks disappear?

2. Nor can it be confidently referred to contraction from cementation. It is difficult to believe that this can explain the amount of shrinking indicated in the figures, though we may frankly admit our ignorance of any quantitative evidence concerning the amount of shrinkage due to molecular cohesion.

3. Nor can we conceive of any chemical reaction producing such loss of volume.

4. The more positive evidence of our view is shown in figures 17, *a*, *b*, *e*, and 22 of plate 50. Compare also figure 5, plate 49, where it is clearly shown that the origin of the concretion is complex; that it has been built by successive additions in the order indicated, and each has shown the same tendency to crack in the interior. In this case the theory of shrinking by drying must be dismissed at once, for it would require not only moisture succeeding drouth repeatedly, but in some way local concentration of moisture and of argillaceous material deposited again and again without any obvious reason. If it be suggested that in some way the shrunken portions were all moist or of peculiar shrinkable nature at the same time, we must explain the more difficult point of seeming succession of crescentic members overlapping one another. We must explain also the still more significant fact that in every case the cracks are broadest toward the center of the whole mass, not toward the center of each member, as we should expect if they were all formed contemporaneously.

5. Another evidence of our view are the signs which sometimes appear around these concretions of their crowding the surrounding strata. In the Benton and Pierre shales a rude, cone-in-cone structure is often developed around them. Again, in the Titanotherium beds, silicious concretions are found to have split the fossil bones in which they form.

6. Another argument may be derived from the analogous behavior of films on evaporating solutions and also in the tendency of crusts around the edge of a liquid to blister up and crack off from the vessel containing them.

The following is a more detailed statement of the process:

First, the collection of similar molecules as in an accretion; but conditions are such that the solidification takes place not entirely on the surface but largely between the particles already deposited, wedging them apart with force sufficient to separate the portion inside the expanding zone, and also to resist and force outward the embedding strata. This may result mainly from the fact that the outer portions have the first chance to appropriate incoming material. It may be thought incredible that molecular cohesion is powerful enough to do this, but when we think of its force when resisting tension it may help us somewhat to understand when it manifests itself apparently in an opposite direction. We say apparently, for really in both cases it is the attraction of molecule for molecule, and the apparent diverse effects are due simply to the different mechanical relations. Indeed, when we think how capillary action may force molecules of water into the pores of wood with sufficient power to split rocks in the quarry, and freezing water has still greater power, it may not be so difficult to believe that

calcareous particles by intercretion may accomplish the results under consideration.

It should be noted further that the first cracking of the interior takes place when the breadth of the growing zone is several times that of the ruptured interior, and that the cracks gradually spread toward the surface as the concretion increases in size by surface accretion. The intercretionary action may in later stages even extend the cracks quite to the surface. This may be made more evident by the study of figures 23 and 16, plate 50.

The compound concretion in figure 17 may be plausibly explained by simply supposing several successive periods of growth corresponding perhaps to as many rises of ground water so as to submerge it more or less completely. The marked cessations in growth which divide the successive portions may have been due to the effects of weathering or oxidation while it was not completely covered by the ground water.

EXCRETIONS AND INCRETIONS

Another method of formation of concretionary nodules is so different that it may be questioned whether it should be classed with the rest under the head of concretions. It is the form which Dana has called "centripetal" concretions.* He applied the term to signify the fact that the final or permanent growth is toward the center. It follows, therefore, that they are not as compact as other concretions, and that the material must first be concentrated either by previous accretion or by unusually concentrated sedimentation. The mineral most frequently showing this action is ferric hydroxide. Ferrous salts dissolving are oxidized to ferric hydroxide when they come in contact with the air on the surface of the containing rock, as in figure 16*a*, plate 49. Such action appears often in ferruginous sandstones and limestones. Such cases can hardly be called concretions. Certain forms of spheroidal weathering, especially those where successive concentric shells of iron oxide are formed, may be explained in this way. Similar action with similar resulting structure, on a smaller scale, may be found within the rock around some moist spot as figures 16*b*, *c*. In such a case the results resemble accretions of a rhythmical structure.

These excretions are frequently hollow. This form is simpler and we therefore consider it first. If an accretion or intercretion of ferrous carbonate like figure 14, either pure or mingled with clay or sand, be reached by water charged with carbon dioxide and oxygen, it will begin to dissolve, and the iron will be precipitated on its surface as ferric hydroxide. The impurity will remain undisturbed. Figure 14 shows

*Manual of Geology, fourth edition, p. 98.

the stages in this process. *a* is the original intercretion, *b* an intermediate stage when the forming shell is separated from the undissolved remnant by a leached zone of the impurity left behind. A photograph of such a stage is shown in figure 13, plate 50. It will be noticed that the oxide forms in the joints of the cracked concretion as well as on the surface. The finished product is represented by *c*, when the cavity of the hollow iron pebble has been opened and the incoherent impurity rattled out. Such may be found in weathered sand and sandstone.

But the form most pertinent to our subject is the nodular form with rhythmical structure, which may resemble certain forms of accretion. This rhythmical structure Dana, with his customary insight, recognized as analogous to the concentric rings formed by a drying emulsion like milk upon a flat surface. We may suppose a similar rhythmical action of forces in both cases. In the emulsion the drying accumulates a film of the precipitated particles where the drying is most active, namely, on the outermost edge. When the liquid loses volume, so that it can no longer fill that limit, it is withdrawn by cohesive attraction considerably within the first limit, where it again stands and deposits another ring till there is a similar necessity of withdrawing again, so that the process is repeated indefinitely. In the case of a concretion, however, we must suppose a vibration between the different influences, for we can not have a volume of the liquid playing against a cushion of air because of the geometrical relations and the inelasticity of water; but we can suppose either an alternating action between carbonic acid and oxygen in the water as the water gradually withdraws by drying, or we may suppose by varying volumes of water corresponding to different showers or other fluctuations of climate. The writer has not seen good examples of this structure, but concentric color lines in weathered rocks are so often found that there seems no good reason for doubting concretionary action of this sort.

There are, moreover, structures resembling those just described, except that the practical surface is a cavity communicating with the outer air. The more common example may be found around root marks, which may be so much coarser than the pores of the surrounding deposits that they may be emptied of water while the latter are still saturated. Hence they form around these root marks concentric cylindrical films of iron oxide having a vertical length equal to the difference in height between the top of the ground water in the root marks and that in the surrounding deposit. Moreover, as these levels fluctuate, these elongated concretions may have greater vertical length. Such concretions of minute form are very common in the loess. A diagram of such is shown in figure 15, plate 49. They are often of minute rhythmical structure, but frequently are nearly solid except the small hole in the center.

Their usual size and shape resemble quite closely a common lead-pencil. Their method of growth, as given above, is a matter of inference rather than positive observation. If those described in the earlier part of this section may be properly called excretions, because the particles move outward to their final deposition, then these may for a similar reason be called incretions; but neither term is wholly satisfactory.

Incretions are often found in the loess composed also of carbonate of lime. They are often like clay pipe stems in form and size. Moreover, they may at certain levels increase by accretion or intercretions into nodules of considerable size, resembling tuberous roots in form and in relation to the stem-like concretions, as is shown in figure 22*a*, plate 49. Such tuber-like enlargements seem more likely to occur near levels where the top of the ground water stands for some time.

Geological Effects

IN GENERAL

Concretions may be considered as a kind of local cementation of unconsolidated strata, and therefore may merge gradually into wholly consolidated strata, which are well known to form the controlling factors of topography. Hence we are prepared to believe, on general principles, that concretions themselves may be very influential in topography.

TEEPEE BUTTES

This striking feature in certain localities on the western plains was ingeniously traced by Mr G. K. Gilbert some years ago to concretions cementing together colonies of *Lucina occidentalis.** All gradations may be pointed out along a certain horizon of the Pierre formation from the sharp, conical knoll to the low mound with the concretions scattered about on the surface. Near the trail between Deadwood and Bismarck the axis of one of these buttes stands completely uncovered in the form of three or four huge boulder-like concretions, each of many tons weight, resting one on another, as though giant hands had piled them there. The relations of these concretions to the teepee buttes is clearly shown in figure 23, plate 49.

BAD LAND PINNACLES

The scenery of the White River bad lands has been long noted for its grotesque and picturesque features. Pinnacles, castellated shapes, pyramids, pillars, spires, etcetera, are found in unlimited numbers. The prevalent deposit is a sandy marl, traversed with irregular strata of sand and gravel. Both in the marl and in the sand many flat concretions have

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* Seventeenth Ann. Rept. U. S. Geological Survey, part ii, p. 569.

been formed. In some cases they merge into one another and form continuous strata, but more frequently they are more or less detached. Under the influence of erosion the latter become the caps of earth pillars which may sometimes rise several feet in height. As the process of erosion goes on rapidly these stand out at different levels on the steep slopes, sometimes as detached pinnacles and at other times as buttresses receding in steps one above another.

Similar effects are found in the dark colored clays and loams of the Laramie which comprises much of the Little Missouri " bad lands."

BUTTES

Studding the plain west of the Missouri in the Dakotas are many isolated buttes which stand out as conspicuous landmarks. They are carved from the Laramie and Fox Hills formations. They remind one of the pinnacles just described on a grander scale. They sometimes rise to 100 or 200 feet in height and may have an area at the top of an acre or more. With a little study one discovers that their tops are approximately on a level, and that this level farther west becomes embodied in a tableland of greater or less extent. The common explanation of these features is that at some time a stratum of sandstone, which is frequently found capping the buttes, formerly extended over the whole region, and that the buttes are the simple results of circumdenudation. Further study, however, reveals the fact that some of the buttes, especially those of the Fox hills, are not capped by continuous sandstone strata, but by layers of more or less separate concretions lying in a bed of sand or loam. In other cases, where the formation is Laramie, while the butte may be capped by a heavy stratum of sandstone in some cases, in other cases only concretions are found, sometimes of gigantic size. It seems, therefore, probable that instead of the sand stratum having been consolidated over the whole region it has been consolidated only locally in concretions which have merged into one another so as to form the stratum capping the first mentioned form, and in other cases they have not become so merged, although they have been near enough together to efficiently resist erosion; hence we may believe that the buttes owe their existence to local consolidation of strata in the concretionary form. This view is strengthened by finding that in the regions farther west, where erosion has not worked so actively, the tableland is capped by a sand stratum, with the consolidation locally developed in the way described. Figures 25 and 27, plate 49, illustrate this theory.

KNOBS

Another topographical effect, and rather more common than the last mentioned, is the formation of knobs of more or less rounded form. In

the last case mentioned a later stage, following the flat top butte, is where erosion has displaced the concretions and left them strewn over the summits and sides of a rounded knob. Such may result therefore where the concretions are largely restricted to one stratum.

More commonly, however, they are distributed through several strata and with more or less uniform prominence. For example, they may occur as lenticular concretions in a bed of shale or in the limestone in the form of flint nodules. In the former case the result follows the washing away of the embedding shale, in the latter case where the limestone becomes dissolved and leaves the concretions resting in a stratum of residuary clay. The form of the concretion has much to do with its efficiency in this respect. Those which are globular are quite apt to roll down the slope and leave the summit unprotected, but in the case of lenticular forms they are apt to keep their position and form a very effective covering. If the concretions crack into angular fragments they become especially efficient in protecting the surface. This is apt to be the case of chert nodules, which have produced the knobs of central Tennessee and southeastern Missouri. Similarly, the large calcareous concretions of the Pierre in Dakota break into angular fragments, so that sometimes a single large concretion may furnish capping for a quite conspicuous knob.

In the case of globular concretions there may be a tendency to form knobs in a secondary stage as follows: In an early stage of erosion they may roll down the sides of a ravine and accumulate in the bends of the watercourse at the bottom. As erosion continues, these bends resist the erosion of the water, which is therefore turned aside, and in the process of ages the general surface of the country is lowered below the level of the accumulation first formed, and it may stand conspicuous as a knob. Action similar to this has been frequently noticed on the sides of the deep valleys carved out of easily eroded material, with stone deposited either in the clays, as in the case of boulder-clay, or where the stony material rests on the top, as the capping of a terrace. Examples of this sort have been noticed in the hillsides of the Missouri valley where it cuts through the Pierre shales overlaid by the terraces and till of the glacial period. No cases can be quoted where concretions have been the sole cause of such action.

NATURAL REVETMENTS

Under this head we may include cases where the concretions have accumulated at the foot of cut banks and steeper slopes bounding rivers and lakes, as in figure 26, plate 49, and figure 2, plate 50. From what has been said in the last section, it may be readily seen that a stream cutting a

bank abounding in concretions will soon have a quantity of them interfering with the further action of its waters. The same may be true also where lakes and the ocean cut against deposits of similar character. Hence concretions have an important effect in limiting the size of lakes and the encroachment of the sea, and they also have much to do with the features of river valleys. A stream cutting through rocky strata of uniform hardness naturally produces canyons bounded by cliffs. In softer strata of uniform character similar features may appear at first, but very soon give way to gentle slopes. In other words, the stream reaches grade easily and swiftly. The effect of concretions is intermediate between these two forms. The upper part of the slopes may cut back to a gentle angle, and yet the stream becomes limited to a more definite channel than in the second case, so that the bottom is not widened, although the valley may be open. Moreover, the stream is not likely to ever have much of a flood plain. Where streams pass through a stratum of concretion-bearing clays with similar soft deposits barren of concretions above and below, there is apt to be a narrower valley and a steeper slope in the concretion-bearing region.

These are some of the more obvious results of a study which, if continued with diligence and discrimination, promises to reveal still more impressively the influence of concretionary action upon physiography and the general history of the earth's surface.

Explanation of Plates

Plate 49.—*Concretions, their Structure and Effects*

Figure 1.—A secretion.

Figure 2.—A geode.

Figure 3.—An intercretion, showing stages of growth by sections through one of globular form.

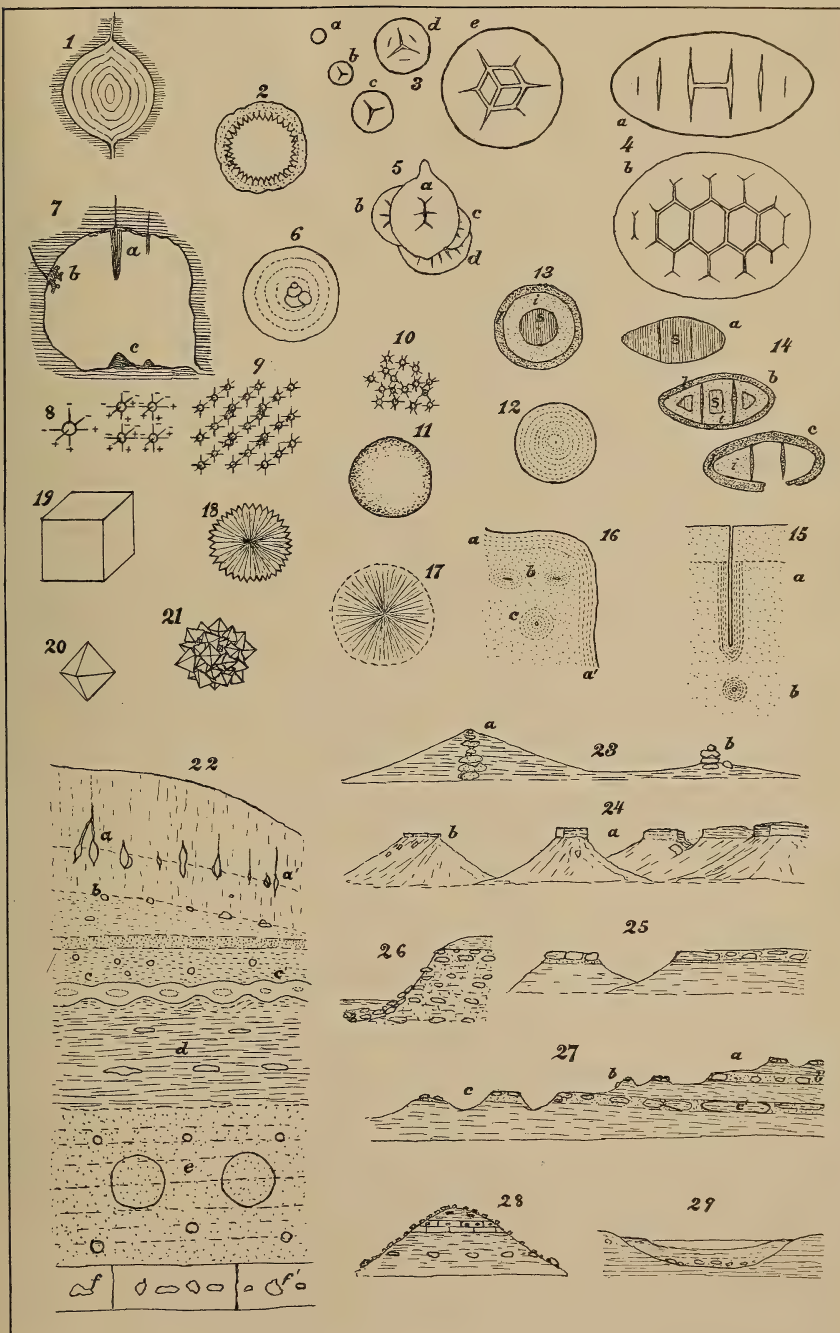
Figure 4.—Sections through a lenticular intercretion. *a*, vertical; *b*, horizontal. When the cracks are filled with mineral it becomes a septarium.

Figure 5.—Section through a compound intercretion like numbers 17 and 22, plate 50.

Figure 6.—An accretion with nucleus.

Figure 7.—A cavern, showing stalactites, *a*, formed by trickling water, and *b*, by seeping water, and *c*, stalagmite, all accretionary growths but not concretions.

Figure 8.—Theoretical diagram of an isometric molecule, showing axes or bonds.



CONCRETIONS, THEIR STRUCTURE AND EFFECTS

FIGURE 9.—Such molecules arranged in a crystal like number 19.

FIGURE 10.—Such molecules irregularly arranged, as in a concretion.

FIGURE 11.—External view of a concretion like number 12.

FIGURE 12.—A globular concretion, showing concentric rhythmical structure.

FIGURE 13.—An excretion, or centripetal concretion, in which iron oxide is transferred from the interior, *s* (siderite), to the exterior, *l* (limonite), leaving behind impurity, *i*, as in number 13, plate 50.

FIGURE 14.—A siderite intercretion, *b*, the same changing to *c*; *c*, the same with siderite dissolved, forming a "hollow pebble" broken on one side so that the impurity is discharged from two chambers.

FIGURE 15.—An incretion forming around a rootmark—*a*, vertical section; *b*, a horizontal.

FIGURE 16.—Excretionary action forming ferruginous shells next the surface of a ferruginous sandstone, *a–a*, and also embedded excretions, *b* and *c*.

FIGURE 17.—A globular concretion showing radiate structure.

FIGURE 18.—Similar, showing crystalline facets on the surface.

FIGURES 19 and 20.—Cubic and octahedral crystals.

FIGURE 21.—A cluster of octahedral crystals.

FIGURE 22.—An ideal section showing forms of concretions, according to character of embedding formation—*a*, loess kindchen, starting as incretions, afterward becoming accretions along the water-table, some of them compound; *b*, irregular nodules in loamy clay; *c–c*, concretions merging into one another, as in many cases including those figured in plate 51; *a–d*, lenticular form in shale; *e*, globular forms in massive sandstone; irregular chert, in limestone.

FIGURE 23.—Concretions including *Lucina occidentalis*, causing a teepee butte—*a*; *b*, the uncovered core.

FIGURE 24.—Buttes caused by a stratum of sandstone.

FIGURE 25.—Similar buttes formed by concretions locally abounding in a stratum of sand.

FIGURE 26.—Concretions forming a revetment by a lake or river.

FIGURE 27.—A more comprehensive view of buttes passing into mesas where erosion has not been so active or where concretions have become more extensive or more numerous.

FIGURE 28.—A knob caused by concretions from different strata.

FIGURE 29. Formation of clay-iron-stone concretions in the sediment of a pond. Eventually by long erosion this may form a knob.

Plate 50.—*Various Concretions*

Figures 1 and 2.—Concretions from river sand.

Figure 3.—Concretion from shale.

Figures 6 and 12.—Concretions of various forms and composition, all accretions.

Figures 7 and 10.—Barite, with radiate structure.

Figures 6 and 9.—From shale with fern leaf nucleus.

Figure 8.—A compound concretion from sandstone.

Figure 13.—An "excretion" showing the siderite nucleus (compare numbers 13 and 14, plate 49).

Figures 14 and 15.—Pyrite and calcareous concretions formed around ammonite shells.

Figure 16.—An intercretion showing cracked interior with cracks partly filled with calcite.

Figure 17.—A compound intercretion, opened to show different members.

Figure 18.—Reptilian vertebra serving as a nucleus for calcareous concretion.

Figures 19, 20 and 21.—Quartz geodes.

Figure 22.—Number 17, with the different members in position.

Figure 23.—Another intercretion, like 16; both are from Benton shales.

Plate 51.—*Log-like Concretions*

Figure 1.—Log-like concretions in Laramie beds, near Camp Crook, South Dakota.

Figure 2. Similar concretions coalescing laterally on North fork of Grand river, South Dakota.

Plate 52.—*Concretion Horizon and Natural Revetment*

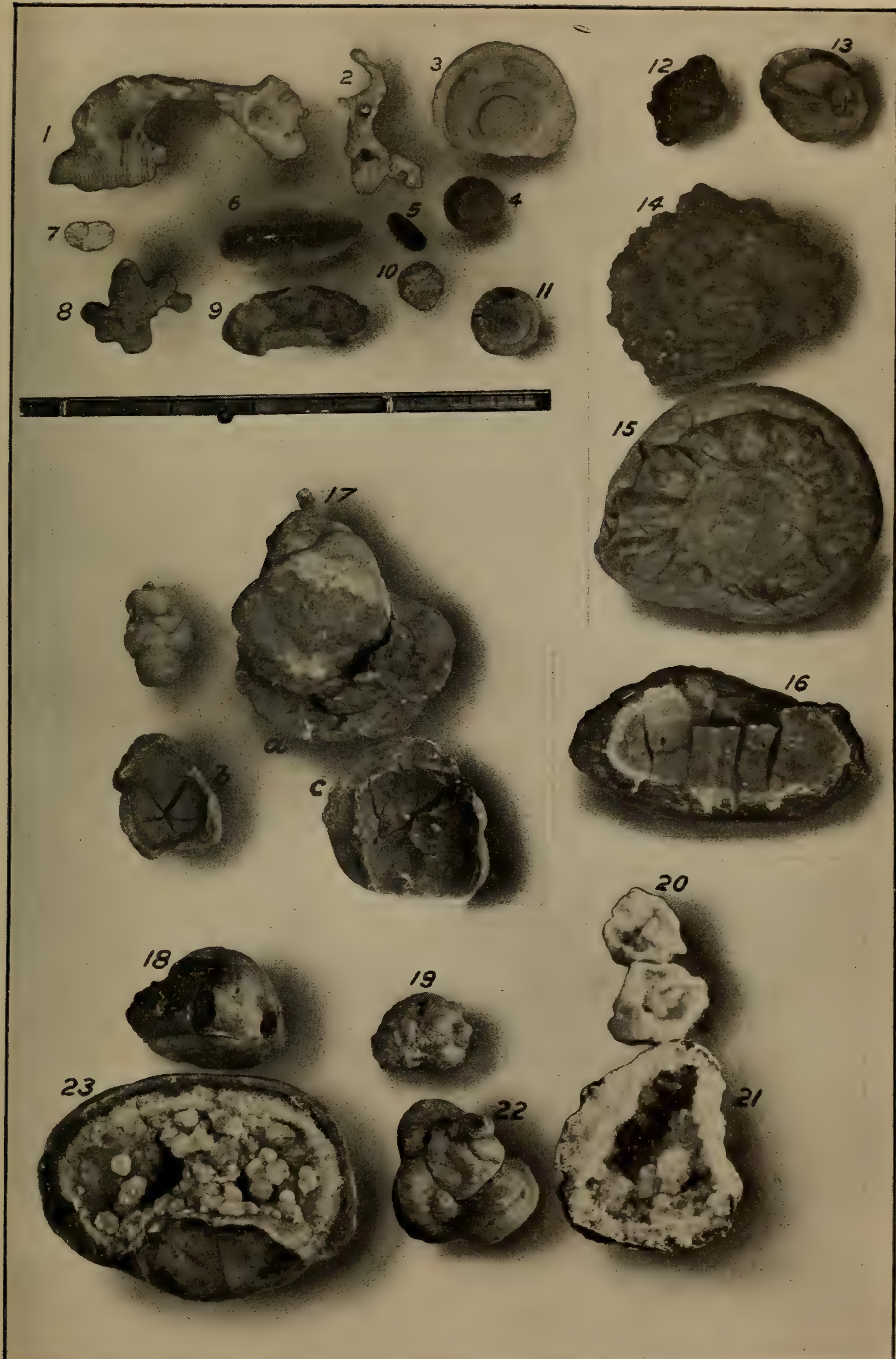
Figure 1.—Concretion horizon in the Laramie, near the junction of Flint Rock creek and Moreau river.

Figure 2.—Natural revetment formed of concretions from the Laramie, on shore of lake in northern Dewey county, South Dakota.

Plate 53.—*Concretions in Wyoming*

Figure 1.—Concretions in Fox Hills sand, near Cooper creek, Wyoming.

Figure 2.—Lenticular concretion showing sand erosion, from the same formation, near Rock creek, Wyoming.



VARIOUS CONCRETIONS

FIGURE 1.—LOG-LIKE CONCRETIONS IN LARAMIE BEDS

FIGURE 2.—LOG-LIKE CONCRETIONS

LOG-LIKE CONCRETIONS

Figure 1.—Concretion Horizon in the Laramie

Figure 2.—Natural Revetment

CONCRETION HORIZON AND NATURAL REVETMENT

Figure 1.—Concretions in the Fox Hills

Figure 2.—Concretions showing Sand Erosion

CONCRETIONS IN WYOMING

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 14, PP. 369-384, PLS. 54-58 SEPTEMBER 30, 1903

STUDIES OF THE GRAIN OF IGNEOUS INTRUSIVES

BY A. C. LANE

(*Read before the Society December 31, 1902*)

CONTENTS

Introduction

It has seemed to me that it would be well in connection with the following paper, which should be read first, on porphyritic appearance to show how the principles and results there stated are used in particular cases. I propose, therefore, in this paper, in the first place, to study the grain of the augite in a group of chemically similar diabases. This is the mineral which seems to lend itself best to mathematical treatment. The comparative results are interesting and suggestive. I will, then, take one of these rocks in Marquette and study the grain of all its constituents to show how we must use our formulæ, with due regard to petrographic observations and scientific common sense.

But first will be illustrated the methods of computation in the case of one rock, which I take to be effusive, the (greenstone) ophite of the Isle Royal report,* which is in chemical and mineralogical composition similar to other rocks.

Augite of the "Greenstone" Ophite

We will take the observations as given on page 245 of the Isle Royal report on thin-sections 15252 to 15258 and reduce the distances to milli-

*Geol. Survey of Michigan, vol. vi, part i.

meters, allowing for fractions not given there. There is, however, an uncertainty of probably at least one-half a foot (152 millimeters) in most of the distances. We obtain the table below:

Section.	Distance.	Difference.	Grain.	Difference.	Rate of difference.	Ax.	B.
15258	0		0				
		296±152		1.25	.00422		
15257	296±152		1.25			.06	1.19
		7,054 "		1.65	.00022		
15256	7350 "		2.90			1.58	1.32
		8,550 "		1.1	.00013		
15255	15900 "		4.			3.42	.58
		6,200 "		1.	.00016		
15254	22100 "		5.			4.74	.26
		6,800 "		2.	.00029		
15253	28900 "		7.			6.2	.80
		8,600 "		2.–	.00023		
15252	36500 "		9–6			7.84	1.16
Average from 15257 to center					.00021	. . . . . .	.885

In this table the observations on thin-section 15258 are uncertain, for it is decomposed, and those on 15252 and 15253 are not very satisfactory, for the grain is so coarse that it would require a number of sections to give us a fair idea. It is obvious, however, that from 15257 clear in to the center, represented by 15252, the gradient is fairly steady and somewhere about .0002, which is what we found for the group on page 129 of the Isle Royal report (.06 / 304).

Taking the gradient from 15257 to the center, we find it to be (9—1.25) / (36,500—296) or .000213. Assuming this gradient A from the margin, we find the column headed "Ax," and the difference between these and observed values will give us the average value of B. These differences are given in the column headed "B." Then we can find the contact zone y', which equals B / A, or 2,400 millimeters.* This is so much less than c, which is more than 73,000, that we see that we are safe in using the approximate formulæ, so far as that is concerned, and c must be 2(36,500 + 2400), or say 78,000 millimeters.

As far as the ratio of temperature is concerned, if we use formula (19)† we shall find that .45 hf^2 will be about $\frac{1}{2}$, and consequently f^2, which is equivalent to u / u_0, will be greater than 1, which is impossible. In fact, the formula for E does not hold when the grain increases to the center, and u / u_0 is too high, say about .90. We may therefore be reasonably

* I believe this is really too high, and that part of the coarseness of grain at the margin, which makes B and hence y so large, is formed in flowing. I suspect y' should be about two-thirds of the value used.

† See page 397.

certain that the initial temperature was but little above that of consolidation. We do not know the gradient close to the margin, and that is the point, anyway, where the convection currents and the earlier crystallization that takes place produces the most irregularities.

For these high values of u/u_0, h changes quite rapidly, and hence we can not determine K with any exactness unless we had C, which is not the case.

Palisade Trap

The great intrusive sheet of the palisades of the Hudson is well known to most American geologists. It has been described by Darton, Kümmell, Andreæ and Osann, and Queneau, besides earlier writers whose works are noted by Darton and Kümmell.*

If we take the observations on grain for this trap sheet, which consists essentially of an aggregate of augite and labradorite with occasional acid interstices containing micropegmatite with small amounts of brown mica and opaque iron ore and a certain amount of hypersthene, we find that all writers refer to a marginal zone in which the grain decreases. The whole thickness, according to Kümmell, is about 300 meters.

If we take one set of Queneau's results for augite given on page 192 and find the linear dimensions, we may construct the following table:

Distance x' in millimeters.	Difference.	Linear grain in millimeters.	Difference.	Ratio of differences.
	390		.0824	.000209
390		.0824		
	1110		—.0132	—.000012
1500		.0692		
	2410		.1283	.0000532
3910		.1975		
	3780		.1855	.0000491
7690		.3830		
	3900		.1660	.0000426
11590		.5490		
	5810		.3070	.0000528
17400		.8560		
	5810		.233	.0000399
23210		1.089		
	11280		.068	.000006
34490		1.141		

*The relations of the traps of the Newark system in the New Jersey region. Bull. No. 67, U. S. Geol. Survey, 1890. See also Size of grain of igneous rocks in relation to the distance from the cooling wall, by Augustin L. Queneau, School of Mines Quarterly, xxiii, 181–195, January, 1902. Contributions from the Geological Department of Columbia University. Amer. Jour. Science, November, 1902, vol. xiv, page 393. Tiefencontacte an den intrusiven Diabasen von New-Jersey, Von Andreæ und A. Osann. Separat-Abdruck aus den Verhandlungen des Naturhist.-Med. Vereins zu Heidelberg. N. F. V. Bd. 1, Heft.

From this table it appears that the increase of grain is irregular at the margin, but that from 1500 to 17400 it is fairly uniform and thereafter it rapidly diminishes.

The ratio of increase of grain or slope is:

$(.8560 - .0692) / (17400 - 1500) = (.7868) / (15900) = .0000494 = s.$

If we suppose s to be A, as seems natural, since the value of the grain at 390 millimeters is greater than at 1,500 millimeters, indicating a curve like .49 of plate 57, we get very small or negative values for B. We are led, therefore, to believe that either there is practically no contact zone or s is C.

As to the grain at the center, we have unfortunately no definite observations, and we don't know with any great exactness the thickness of the Palisade sheet at the point of observation. But if we start with the coarsest grain observed and suppose the increase to continue to the center at the last observed rate, and also suppose the center to be about 100 meters farther in, and all these suppositions are probably not far from the truth, we shall find E to be somewhat less than 1.8. This value we will take in our calculations. We will also assume that c is about 300 meters, then for the ratio of u / u_0, if we suppose there is no contact zone and B is 0, $E / .45\, hsc$ will be .327. But it is difficult to imagine that the magma was injected three times as hot as the temperature of consolidation of augite with no effective contact zone (which Andreæ and Osann have shown exists as a matter of fact) and without melting down the country rock very markedly. Moreover, such initial temperature would lead us to find practically the same belt of increase of grain for the feldspar. This is not true, for the feldspar continues to increase at a rapid rate farther in than the augite. We are again led to try the other alternative that the slope .0000494 represents C. From this supposition we shall find the following equation:

$$2u / u_0 = 1 + (.327)^{\frac{2}{3}} (2u / u_0)^{\frac{1}{3}}$$

Whence we can find the ratio u / u_0 .774, but for this value of u / u_0 we shall find that h' is .85 instead of .88, and this will give us a revised value of u / u_0 of .78.

Moreover, noticing that the values of Cx' hold closely for the grain up as far as 17,400 millimeters, we may infer from equation 21 of the previous paper that $2y$ is not less than 17,400/.55 or 31,600 millimeters, so that the thickness of the dike would be for the assumed value of c (300,000 millimeters) about 269,400 millimeters, which agrees well enough with Kümmell's estimate. The width of the contact zone would then be about 15,800 millimeters, and Andreæ and Osann have shown that there is a well marked contact zone of new crystallization of notice-

able width. We shall further find for K a value near 4.8, and for $a\sqrt{u_0}$ the value .000016.

We notice that the initial temperature appears to be relatively higher in the intrusive sheet than in the surface flow of very similar composition. This might mean that the magma itself was hotter or that the country rock was hotter or both.

We must, however, observe that the curve of grain, especially at the margin, suggests a curve of the type of .49 of plate 57, and that by taking s within the limits of the error of observation, for instance, .000047, we could bring it under this type; but the contact zone would have to be very small, and this would be especially forced in view of the high initial temperature which would be implied. The other explanation of this somewhat greater grain at the margin would be that the effect of stirring and cooling, down to the point of formation of augite before motion has ceased, had produced the observed effect.

In passing, it will be interesting to compare the grain of the feldspar, for which we have the following table:

Distance.	Difference.	Grain in millimeters.	Difference.	Quotient = s.
			.053	.00013
390		.053		
	1110		.0265	.000024
1500		.0795		
	2410		.0800	.000033
3910		.1595		
	3780		.1245	.000030
7690		.2840		
	3900		.0210	.0000054
11590		.3050		
	5810		.1100	.000019
17400		.4150		
	5810		.1420	.000024
23210		.5570		
	11280		.1230	.000011
34490		.6800		

The average gradient s from 1,500 to 17,400 millimeters is .000021, and it is obvious that the gradient remains equally steep up to 23,210 and perhaps beyond. This is farther than in the case of the augite and is an indication, by equations (18) and (19) of page 397, that the period of formation of the feldspar is earlier than that of the augite, its temperature of consolidation being nearer the initial temperature. This is true, as Andreæ and Osann have remarked on page 4. From this we should compute an average gradient s of .000022, and if we suppose s to represent A and compute B we find half the values of B will be possible negative values.

We are therefore justified in assuming that s is equal to C—that is, $.5570 / 23210 = .000024$. This value for C will make Cx' satisfy all the observations with errors well within the limits of error of observation. If the feldspar is formed before the augite, u / u_0 must be greater than .78 and the grain at the center must be between $s\ .2w$—that is, 5.8 millimeters and a value to be found from equation (15), of page 396, or 2.66 millimeters. Now, Kümmell says that at the center the thin tabular crystals are $\frac{2}{8}$ to $\frac{3}{8}$ inch in diameter, but judging from Queneau's photographs of the general habit of feldspar in diabases we may safely assume that the thinness is about $\frac{1}{4}$ of the breadth. This should make the mean dimension of sections at right angles to the pinacoid M from 3 to 4.5 millimeters in linear dimension—that is, in area 9 to $20\frac{1}{4}$ square millimeters, so that there is a fair accordance.

Diabase Dike at Light House Point, Marquette

The grain of the Light House Point dike was somewhat discussed by me in the Isle Royal report,* but I made the mistake of not considering the ambiguity as to whether the gradient on increase was $Ax' + B$ or Cx'. The average observations on a set of sections more recently taken, July 17, 1902, are (accuracy of measurements not over 10 per cent)—

Distance.	Difference.	Grain in millimeters.	Difference.	Ratio s.	Ax'.
0		.046			
	50		—.028	—.00056	
50		.018			.0275
	125		.061	.000485	
175		.079			.0965
	231		.137	.000595	
406		.216			.223
	355		.194	.000518	
761		.410			.419
	861		.259	.000303	
1622		.669			
	6608		.344	.000052	
8230		1.013			

The specimens at 8230 is from the center of the dike, so that $2w$ is 16460 millimeters. The specimen at 1622 millimeters was taken at what seemed to be the end of the zone of increasing grain, and it is obvious that if the rate of increase which holds from the margin up to 761 millimeters continued the grain of the augite would there be .9 millimeters, or nearly the same as at the center, so that the field estimate was not very far out of the way.

* Pp. 243 to 245.

The slope of the zone of increasing grain or that of a tangent to the curve of the grain is obviously near .0005 +, the average increase from 50 millimeters to 761 millimeters being .392 / 711 or .00055. In the Isle Royal report I neglected to consider the chance that this might be C, and assumed that there was no contact zone—that is, that B was practically 0. Substituting the corresponding values of g'' and x' in equation (8) and any value of A over .0005 we get values of B mainly negative, that is impossible, so that if s is A we must most plausibly assume B to be 0, and our best value of s will be .000539, and then we shall have for u / u_0 the value of .286. But if we assume that s represents C, then we shall find for u / u_0 .748. The correction for h is not worth while. We have then to settle the question whether the curve is of type of curve .30 of plate 57 or curve .60 or .90 of plate 58. To settle this question we may note that, supposing B and y are practically 0, from page 393, if x' be 1622, we shall have m_0 equal to 16460 m / 1622 or more. But this will be true if m_0 is about 2.64 and m about .26. Now, in case u / u_0 is .286, as supposed above, it is also true that u / u_0 is P_m, and accordingly that the equation $g' = Ax + B$ should still be reasonably applicable. This is, however, not the case. Besides this, we have all the arguments which we used in the Palisade trap for not assuming the small ratio of u to u_0.

On the other hand, if we wish to get an idea of the width of the contact zone, we may suppose s is C, and substitute the values: $g' = .669$; $E = 1.1013$, and we shall have the following equation:

$$.669 = \frac{1.013}{.45} \cdot \frac{(x' = 1622) + y}{16{,}460 + 2y} \frac{1}{.68}.$$

From this equation we find the value of y about 3,000 millimeters, and it is worth noting that this will change the value of c, which we have, in finding u / u_0, taken as $2w$, from 16,460 to 22,060. Substituting this corrected value, we can find more accurate values of the other data. For instance, $2\,u / u_0$ becomes $1 + (1.013 / .45 + .88 + .000539 + 22{,}060)^{\frac{2}{3}} (2\,u / u_0)^{\frac{1}{3}}$ or $u / u_0 = .70$.

The relative grain of the other constituents is given later.

We have $K = 2.68$ and $k / a\sqrt{u_0} = .00012$.

The three equations of the three tangents to curve of grain are accordingly:

$$y = g' = .000539\, x'.$$

$$g'' = .0001665 \left(\frac{10}{16} x' + 3000\right) = .0001\, x' + .5.$$

$$g''' = 1.013.$$

A second set of specimens were collected by Mr F. E. Wright at another point not far off, where the dike is about 15,200 millimeters wide, and the contact with the Mona schist is 20 paces east of the fence at the foot of Circle street, Marquette. We had one section which was made 5 centimeters long, to cover the 50 millimeters next to the contact. This shows that even at the margin the increase of grain is not so much greater as it would have to be if the slope we have called C were A.

The results of observations at different distances are given below. It must be remembered that when the grain is very fine it is difficult to get an accurate idea of it. The average grain for the three center slides agrees well with what we found before. E is 1.07. Up to 670 millimeters the rate of increase C is .00046, which is quite as near to that previously found as we could expect, but the grain of the augite in number 4, at 1,890 millimeters, is certainly much finer, and that at number 6, at 4,115, perhaps somewhat coarser than normal. I have made repeated sets of observations on number 4, and can only account for the fineness as due to some initial irregularity of temperature or composition.

Distance.	Difference.	Grain.	Difference.	*S.*
0		0		
	10		.012	.0012
10		.012		
	10		.005	.0005
20		.017		
	10		.006	.0006
30		.023		
	10		.009	.0009
40		.032		
	10		.010	.0010
50		.042 .04 *		
	400		.123	.00031
456		.165		
	166		.145	.00087
670		.310		
	1,274		.12	.00009
1,890		.43 to .59 * .444 *		
	2,225		.83	.00039
4,115		1.26 1.00 *		
	1,645		—.52	
5,760		.78 .93 *		
	1,840		.39	
7,600		1.17 1.1 *		

Medford Dike

The grain of the Medford dike is described in discussing the porphyritic

* Figures obtained upon revision, the second set of five sections, not quite so carefully measured. As there is none of the country rock visible in section 1, a few millimeters should perhaps be added to the distance. A further discussion of this dike will be left till later.

appearance in the succeeding paper, and we find there that u/u_0 was .5055, K is about 3, and $k/a\sqrt{u_0}$ is .00002.

Suggestions as to comparative Initial Temperatures

It is worth noting in comparing these rocks, which are in some respects so similar, that the initial temperature is nearest the temperature of the consolidation of the augite in the overflow. It is higher in the intrusive Palisade trap, still higher in the small dike, and highest of all in the large dike, which really might almost be classed as a gabbro. It is easy to see that if the initial temperature were a little higher we should have no marginal zone of finer grain whatever. This would be true if the molten magma were initially hotter or if the country rock were hotter, so that it would probably be true of any rock injected at a greater depth than the Medford diabase.

It may be worth while to remark also that if Lord Kelvin's theory that the earth is a cooling globe is correct, then the depth at which plutonic conditions of grain would be attained would have been much less in earlier geological times than at the present day ; for at a given depth the country rock would have been hotter and the magma from a given depth below would also have been hotter. This may be another reason beside their greater exposure by erosion why plutonic rocks are rather more frequent in the earlier ages.

Other Minerals of the Marquette Dike

Returning once more to the Marquette dike, we will describe what we see in the sections without burdening our text with any more figures and computations.

Taking the feldspar first, we find that sections within 2 or 3 inches of the margin show a pronounced porphyritic texture. Many of the crystals have obviously been formed while the magma was still in motion, and are arranged most abundantly with their flat sides more or less parallel to the margin. At the same time there is really no absolute line to be drawn between these phenocrysts or rhyocrystals and the feldspar of the groundmass. This is especially true as we go farther from the margin. Even at 100 or 200 millimeters from the margin there is still some trace of the rhyocrystals, but by this time there is no definable distinction in size, and by the time we have got 600 or 700 millimeters in two generations are no longer definable. The natural inference is that the feldspar for a few inches next the wall began to crystallize before the magma had come to rest. As we continue our study of the grain toward the center, we find the feldspar becoming coarser and coarser,

and this continues clear to the center. At about the same distance from the margin (600 millimeters) at which the porphyritic texture ceases we commence to find the interstices of micro-pegmatite, with the associated biotite, apatite, and hornblende, which I have described at such length in my Isle Royal report. As we proceed toward the center of the dike, they become coarser, better marked, and the apatite in them, I think, a shade larger. This increasing coarseness of grain, however, I do not take to be a mere matter of cooling, but due to the fact that in the process of consolidation of the dike it solidified first at the side, and then the more soluble residue represented by these interstices was squeezed toward the center.

When we come to study the magnetite, we find that increasing from nothing or an imperceptibly fine dust at the margin clear and continuously to the center, and for this, as well as the feldspar, we are constrained to believe that the formation took place in the very earliest stage of cooling.

The olivine is exceedingly interesting. Sharply defined phenocrysts of olivine are visible right up to the very margin, and they increase in size somewhat for a while as we shift our point of view farther from the margin. This shows that though like the feldspar, they may have commenced to form before the dike came to rest, they were not very large then and increased and continued to grow afterward, but as we continue toward the center we find that they do not continue to grow, or rather that we can not depend on it. We will find occasionally quite a large grain, but our curve of average grain may not increase at all. This does not, however, mean that the olivine belongs to the same period of formation of the augite, for a study of the grains shows that while at the margin they have sharp well defined forms, such as olivine crystals have, at the center they are very likely to be in the irregular corroded grains and are much rarer, anyway. A study of the slides makes it perfectly plain that what has happened is this: The olivine did crystallize out quite early, yet for the most part not before the dike came to rest. It was probably quite coarse at the center. After it had formed, however, the concentration of the salic residue, which we have already described, altered the chemical composition of the magma at the center, and it was corroded. Probably some of it went to form augite, but part of it went into the biotite.

Franklin Furnace Minette

Queneau gives quite a complete study of the grain of the biotite and apatite of the minette dike at Franklin Furnace, New Jersey, the width of which is .61 millimeters. From the tables of grain of the biotite it is

evident that there is a sharp flexure at about 390 millimeters. We have for the average slope of the two sides between 76 and 180 millimeters, $s = .000575$. We can not determine whether this slope is A with a contact zone of 87 millimeters and $u/u_0 = .22$, or whether the contact zone is greater and this C and u/u_0 is .785. The apatite increases clear to the center, and the question then arises whether this is due to the fact that it is formed at the earlier stage of cooling—earlier than the mica—or whether it, as the apatite at Marquette, is affected by a process of segregation. The fact to which Queneau calls attention, that the crystals, although they vary in size relative to the margin, are fractured, would indicate that they were formed at an early stage, and that a little motion in the viscous magma took place afterward.

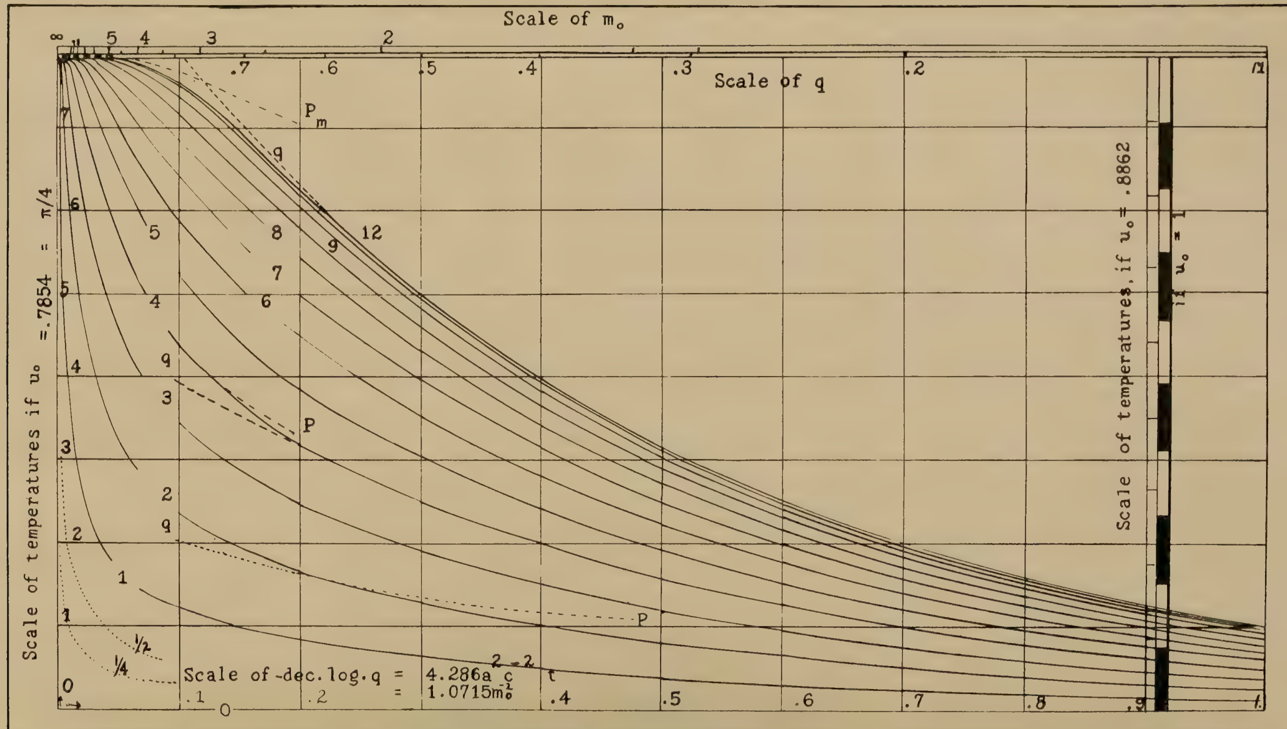
Apatite from the Minette Dike

Distance.	Difference.	Dimensions.	Difference.	Ratio of difference.
00		.0264		
76	76	.0490	.0226	.000297
180	104	.0750	.0260	.000250
380	200	.0877	.0127	.000063
1020	640	.1590	.0713	.000110
3050	2030	.2440	.0850	.000040
6100		.0360		
6030	70	.0550	.0190	.000271
5920	110	.0830	.0280	.000254
5710	210	.0825	.0005	.000002
4880	830	.1070	.0245	.000029
3050	1830	.2440	.1370	.000074
		Biotite Mica		
00		.083		
76	76	.130	.047	.000618
180	104	.187	.057	.000548
380	200	.213	.026	.000130
1020	640	.298	.085	.000130
3050	2030	.324	.026	.000012
6100		.0550		
6030	70	.0850	.0300	.000428
5920	110	.1510	.0660	.000600
5710	210	.2790	.1280	.000609
4880	830	.3260	.0470	.000056
3050	1830	.3240	.0020	.000001

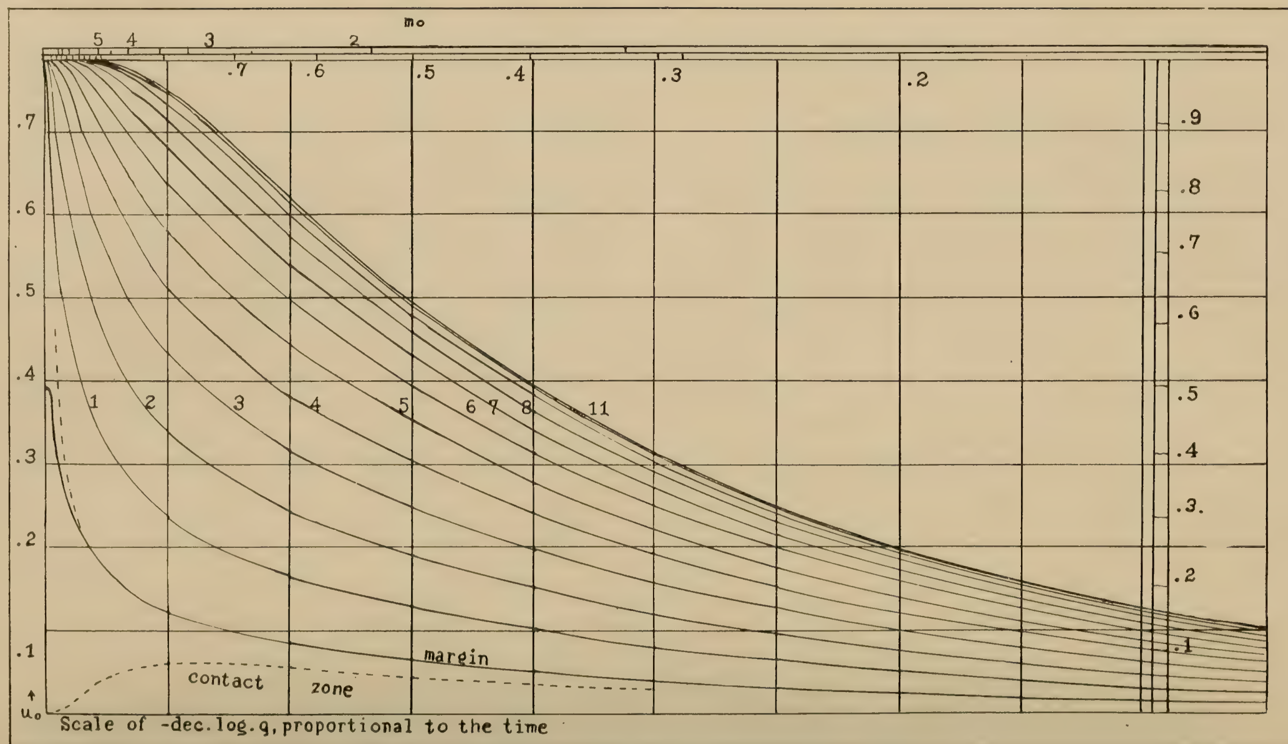
Explanation of Plates

Plate 54.—*Curves of Cooling—Margin Temperature Constant*

This shows the cooling of an igneous sheet, the margins of which are kept at a constant temperature, taken as 0° and represented by the bottom line of the diagram. The temperatures are represented by ordinates, and three different scales of temperature are given, corresponding to different values of the initial temperature. The main scale at the left is the same as used in the Isle Royale report. To the right is the scale if, as is assumed by Queneau, $u_0 = .8862$, and also if the initial temperature of the igneous sheet (that is, its excess of temperature over the surrounding rock) is taken at 1. The abscissas to the right represent the lapse of time, the main scale at the bottom being proportional to dec. log. q and t, and the scales above being proportional to m_0 and q, which are defined in the text. Curves for twelve points from the center to the margin are drawn in full lines, and in dotted lines two curves still closer to the margin, one twenty-fourth and one forty-eighth of the distance to the center respectively. Also for curves 12, 4, and 2 we indicate by dashes the points where the curves of the approximate solutions which we have used in practice leave the curve which we have taken them to represent, to show how small the error is which we make in using them.



CURVES OF COOLING—MARGIN TEMPERATURE CONSTANT



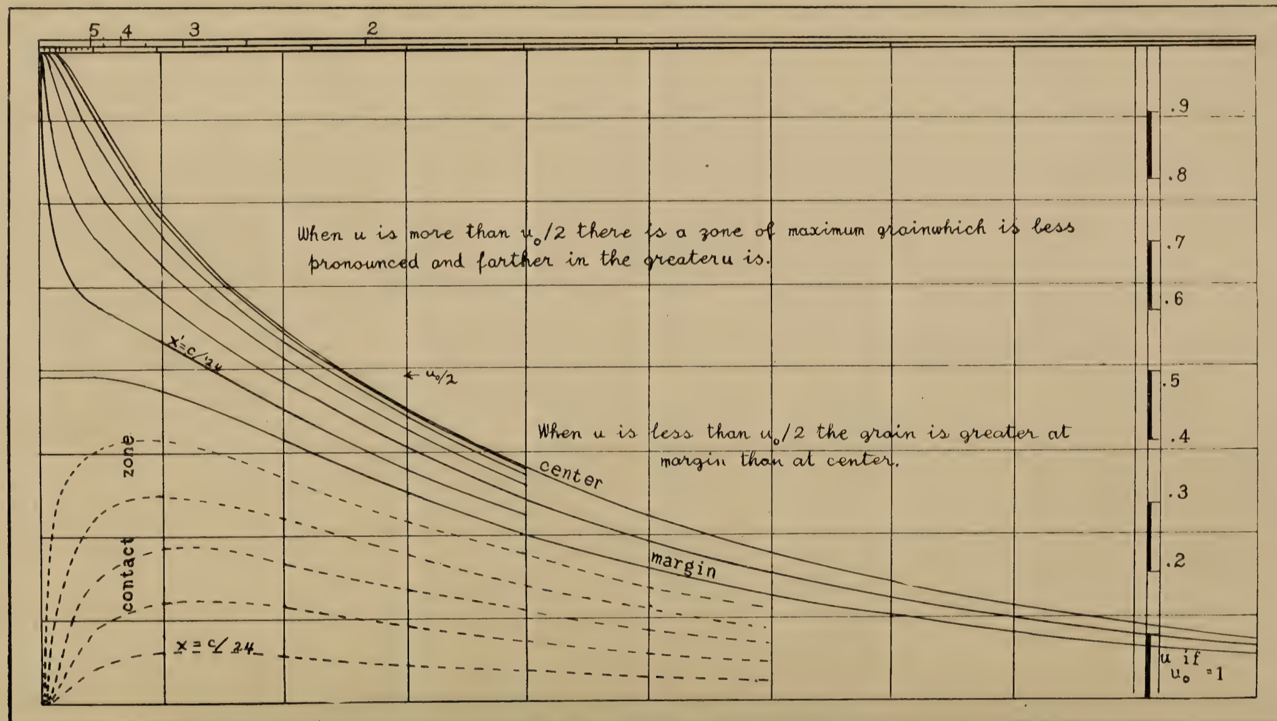
CURVES OF COOLING—NARROW EFFECTIVE CONTACT ZONE

Plate 55.—*Curves of Cooling—Narrow Effective Contact Zone*

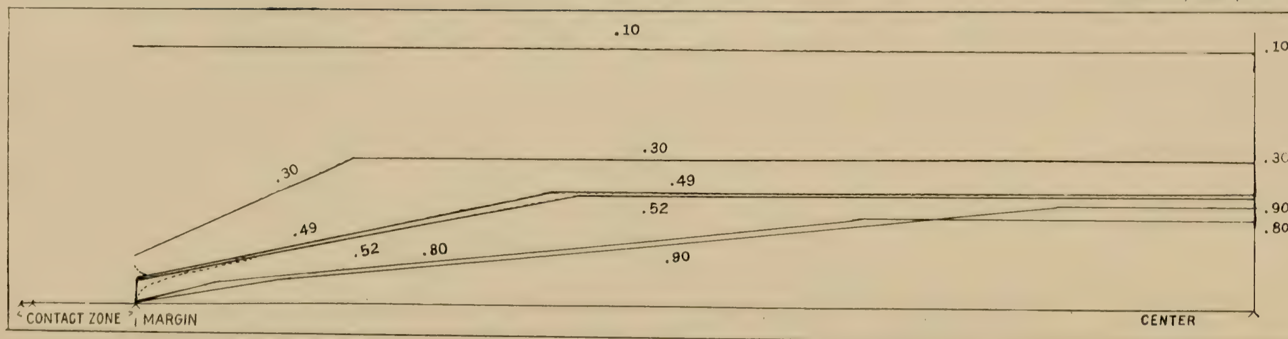
This diagram is similar to plate 54, except that a contact zone is shown in dashes, and also the curve of plate 54, marked 1, and the point where it coincides with the temperature of the margin in this case. Scales are the same as in plate 54.

Plate 56.—*Curves of Cooling—Effective Contact Zone Broad*

The temperatures of an igneous sheet with a contact zone of equal width are indicated by ordinates, the lapse of time by the abscissas measured from the beginning at the right. The curves are temperature curves for various distances from the margin of the zone affected. The full lines represent temperatures of the heated masses, the lines in dashes temperatures in the contact zone. The scales are the same as in plate 54.



CURVES OF COOLING—EFFECTIVE CONTACT ZONE BROAD



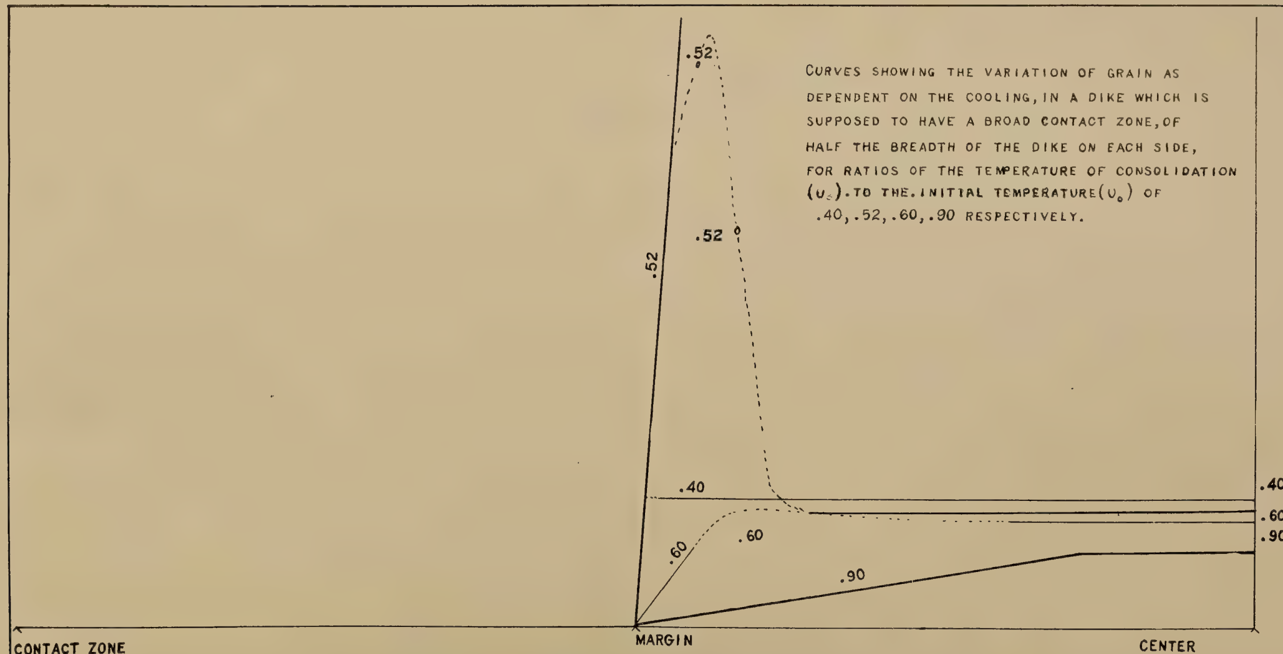
TANGENTS TO CURVES OF GRAIN—NARROW CONTACT ZONE

Plate 57.—*Tangents to Curves of Grain—Narrow Contact Zone*

This plate is based on plate 55, and is for similar conditions. The full lines show tangents to the curve of grain of an injected igneous sheet (supposing the same to be proportional to the square root of the slowness of cooling) as derived from the approximate equations referred to in the text. The position of the point relative to the margin is represented by horizontal coördinates, the average linear dimensions of grain corresponding by vertical coördinates, while the decimals attached to each curve show the ratio corresponding to it of the consolidation—to the initial temperature. The lines in dashes are the actual curves sketched in, where they diverge markedly from the tangents.

PLATE 58.—*Tangents to Curves of Grain—Broad Contact Zone*

This plate bears the same relation to plate 56 that plate 57 does to plate 55.



TANGENTS TO CURVES OF GRAIN—BROAD CONTACT ZONE

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 14, PP. 385-406 SEPTEMBER 30, 1903

PORPHYRITIC APPEARANCE OF ROCKS*

BY ALFRED C. LANE

(*Read before the Society December 31, 1902*)

CONTENTS

OBJECT OF PAPER

The variation of the texture of igneous rocks as the margin is approached has long been recognized, and references to marginal and "Rand facies" phenomena are not infrequent. Yet generally they lack exactness, for in but few cases have the exact distances of specimens of an igneous rock from the margin been noted. Yet a little thought would lead one to expect important aid to the petrographer who wants to know the origin of things from studying just these marginal sections, and especially a series at known distances from the margin, since every one knows what a difference has been made in paleontology by the studies of successive stages in the development of a form, and we may find similar light at the margin of an igneous rock on the different generations of crystals and phenocrysts. For instance, if, as Michel-Lévy says, there are two generations even in granitic rocks † only with similar products, we may perhaps find that toward the margin the younger generation grows finer and the texture will become plainly porphyritic.

* Plates referred to are those of previous article "Studies of the grain of igneous intrusives."
† Structures et Classifications des Roches Eruptives, 1889, p. 29.

But should this always be true, and are porphyritic crystals always intratelluric? In answering this question * and questions of relative age of formation of different minerals, a series of specimens taken at various known distances from the margin will be of great value. That is what I wish to show.

Conceivable Classes of Phenocrysts

It may safely be assumed as possible that the earth's interior is solid. Being under great pressure, it will naturally be in the form of greatest density, which is the crystalline. At times under certain conditions (I presume usually relief of pressure in part) it liquefies or fuses, and then later by restoration of pressure, loss of heat or water or gases (the *agents minéralizateurs* of French writers) becomes solid again, and in the meantime may have flowed more or less freely, being erupted or intruded into new surroundings. There is no reason why the process of liquefaction and solidification, in whole or in part, may not be many times repeated.

Now, the larger crystals or phenocrysts, which give the porphyritic appearance, may be of at least five classes, diverse in origin:

1. They may be relics of an early stage of slow consolidation within the earth (they can hardly date back to the days of the "planetessimals")—be unliquefied fragments of the rock which furnished the magma.

These have corroded outlines and are akin to Lacroix's † "enclaves homœogenes."

The quartz phenocrysts of many porphyries, and the hornblende and mica phenocrysts of many basalts, I should refer to this class.

2. They may have been formed during an eruptive act which took place within the range of the conditions (temperatures) of their crystallization, so that they formed as they were borne floating along. This is the origin of many porphyritic crystals of feldspar, with sharp outlines and fluidal arrangement, either of themselves or of the flow lines of the surrounding magma. It seems likely that sharp zones of alternately varying composition would be especially characteristic of this class, the magma being changed slightly by mixing, while a gradual and uniform change in the composition of a crystal might occur while the crystal grew in a magma at rest.

It is important to note, since it renders a confusion with another class more likely to occur, that these rhyocrystals or floating crystals will naturally be formed first near the margin, where its chilling effect is felt,

* Asked already by L. V. Pirrson, Am. Jour. Sci., vii, 1899, p. 271.
† Les Enclaves des Roches Volcaniques, 1893.

though they may afterward be swept into the center by the current. It is also possible that the crystallization of one mineral may proceed throughout the magma and motion take place afterward. Cases of this I refer to later.

3. If the conditions of consolidation of a mineral are close to those which the magma had when it reached its destination, its grain will increase continuously to the center, while later formed minerals will have a narrower zone of increasing grain. In such a case the mineral will be more prominent at the center than at the margin, must be among the earliest of the last generation, and indeed may very likely have begun formation during the eruptive act, and so have a core which belongs to class 2.

4. If the conditions of consolidation of a mineral are nearly half way between those of the magma and the country rock into which it is injected, then the physical condition of the margin will be nearly that of slowest cooling, and very large crystals may be formed there. These crystals may be earlier than some, later than others in order of formation, but I think usually late.

Theoretically, if the temperature were just half way, the grain at the margin, supposing the mineral to be formed at that temperature, would be infinitely greater than that at the center. In plate 58 the curve marked .52 shows the variation of grain from center to margin, supposposing the temperature of formation of the mineral were .52 of the initial temperature of the magna, that of the country rock being taken as 0°. Practically, however, no mineral is formed exactly at any one temperature, and the real effect should be that the grain near the margin should be under these conditions very irregular for a narrow belt and exceedingly sensitive to slight variation, ranging from great coarseness to great fineness, just as we see in plate 58 that for a fifth of the way in it makes a big difference whether the initial temperature is such that the temperature of consolidation is .40 or .60 or .52, but thence in toward the center it makes much less difference.

5. Finally, there are crystals, notably of staurolite and chloritoid (but garnet, biotite, hornblende, epidote, and other minerals also occur similarly), which are extra large, but are produced by later slow metamorphic action in sediments as well as igneous rocks. They are often honeycombed, canaliculated with cavities and enclosures of the other constituents.

These five kinds may be distinguished as food, floating, early, border, and metamorphic crystals or phenocrysts. If the distinction of these classes is important enough to call for uniform names in all tongues,

these terms can be turned into brotocrystals, rhyocrystals,* eocrystals, oriocrystals, and metacrystals respectively.

The discrimination of these classes is important from the point of view of genesis, and it is easy to see that sections at the margin where the development was arrested might be preeminently instructive, especially in comparison with a series of sections toward the center. The food crystals will be larger, sharper, and less corroded than at the center. Flow crystals will be there if anywhere, and may be nowhere else, and though they may be smaller than they are farther from the margin, if group 2 blends with group 3, the difference between them and the ground mass will ordinarily be more marked. Along near the margin the friction of the walls will produce eddies and send in cooler currents into the mass, so that porphyritic flow crystals may be produced of which the center of the rock mass may be entirely destitute, the temperature having remained too high for any crystallization until well after the magma had come to rest.

When the magma comes to rest, relatively cool spots produced either by flow currents or the absorption of fragments will, if they are not thereby chilled to below the crystallization point of the mineral which we are studying, be points of extra slow cooling and extra coarse grain.

Border crystals, oriocrystals, will most differ in size from the other constituents, and the difference between them and the flow crystals is that they will grow smaller toward the center.

The third class, the early crystals, will be least conspicuous toward the margin, most so toward the center. Ordinarily we hardly class them as phenocrysts.

As I have remarked, the formation of a mineral may occur during the epochs characteristic of the second and third classes, or a core of the first class may be built on by the latter. In such cases the distinctions made will be blurred, though it is often not impossible to distinguish the parts formed in different stages of growth. Such cases must be treated individually.

All the phenocrysts except the early formed and the metamorphic, which are not ordinarily classed as such, will be best developed near the margin. While arrangement in glomeroporphyritic aggregates or envelopment by flow lines are distinctive of the first two classes, corroded outlines and magmatic reaction rims are not infallible signs of the first class, for, as I have shown for the olivine of the Keweenawan traps, during the process of solidification there may be a concentration of certain constituents of the magma which may lead to an attack of the earlier formed

*F. E. Wright.

minerals. The olivine is attacked at the center of the diabase dikes by the concentration of a salic (waterglass) residue.

I wish, however, to call especial attention to the early formed and border phenocrysts, the third and fourth classes, whose very existence has been almost overlooked except by Pirrson* and a few others.

I will consider as briefly as may be the theoretical basis on which the assumption that such crystals may occur rests. Those who are willing to take this for granted and the resultant plates, table, and formulæ may skip the next section, which depends on the calculus, although this does not appear in the approximate formulæ derived.

For the conclusions that we shall draw to be generally applicable, it is by no means necessary that the case in nature should be extremely close to the mathematically assumed conditions. B. O. Peirce has shown that in the case of cylinder whose radius is twice its thickness it makes but little difference with regard to the final axial temperatures, if the top and bottom are kept at certain fixed temperatures, what intermediate temperatures the cylindrical surface has. Similarly, it is by no means necessary that the igneous sheet should be infinite or very regular for our results to apply in a general way.

Differences in diffusivity and convective currents, absorption of heat by evaporation, and similar factors may be in part allowed for by supposing that the contact zone, whose temperature is assumed to vary, is of suitable width. The mathematically effective contact zone will then not necessarily be of the same width as the actual. At the same time, near the margin there may be a cooling effect carried in by currents from the friction of the side which will disturb the temperatures; but initial irregularity of the temperature, which may occur, and which will naturally follow flow lines, will tend to smooth themselves out and be most apparent only in crystallization at the higher temperatures and earlier time. Around inclosures there may be spots thus cooled, which will, according to circumstances, have either an extra fine grain or an extra coarse grain.

Application of the Theory of cooling to Questions of Grain

In my Isle Royal report† I treated of the theory of a cooling slab and its application to the grain of a dike or sheet. A recent treatment is given in Byerly's text-book on Fourier's series.‡ I had called my old teacher's attention to the geological interest of this case, and the solution

* Loc. cit.
† Geol. Survey of Michigan, vol. vi, part i.
‡ Page 105.

of example 1 is equation 11 of the Isle Royal report. Recently Woodward and Queneau have made an addition to the theory of practical importance. It will be simpler first to consider that the sides of the dike are kept at a constant temperature, which we shall take at 0°, and then proceed to a more general case, leaving the mathematical treatment to a separate place.

Marginal Temperature kept Constant

From a mathematical solution of this case, which is illustrated in plate 54 and the Isle Royal report, we find that close to the margin the grain is dependent on the distance therefrom by a comparatively simple formula (the same as Eq. (8) below, letting y and $y' = 0$). Near the center the grain does not vary with the distance from the margin, but is given by formula (9), and only depends on the ratio of the temperature of consolidation to that of the initial magma. These two approximate formulæ may, if we represent the grain by a curve whose ordinates are proportionate to the coarseness of the grain and whose abscissæ are proportional to the distance from the margin, be considered as tangents to the true curve of the grain, which it will follow very closely except for small easement curves near their intersection.

An interesting question is where these two tangents meet—that is, where would the grain be equal to that of the center if the rate of increase at the margin kept up? We have for this a very simple formula:

$$(1) \qquad \frac{x'}{c} = \frac{h\sqrt{2}}{\pi} \cdot \frac{u}{u_0} = .45\, h \cdot \frac{u}{u_0},$$

where x' is the distance of the point sought from the side of the dike c, its breadth, and $\frac{u}{u_0}$, the ratio of the crystallization temperature to that at the beginning, the fixed temperature at the margin being taken as 0°. In this formula h, which is given in table I, will run from .866 down, so that we have almost directly a connection between the ratio of the breadth of the zone of increase to the relative temperature of consolidation, and the greater the latter the greater the former. This is the basis for the existence of the early formed and centrally occurring phenocrysts or eocrystals.

TABLE I.

$P_m = u/u_o$	m	$h = \sqrt{\frac{m^3 D_m \; u/u_o}{(u/u_o)^3}}$
0	0	
.1125	.1	.88
.2227	.2	.88
.3286	.3	.88
.4284	.4	.88
.5205	.5	.88
.6039	.6	.87
.6778	.7	.87
.7421	.8	.86
.7969	.9	.85
.8427	1.0	.83
.8802	1.1	.80
.9103	1.2	.78
.9340	1.3	.75
.9661	1.4	.70
.9763	1.5	.67
.9838	1.6	.64
.9891	1.7	.55
.9928	1.8	.49
.9953	1.9	.45
1.0000	∞	.00

CASE OF THE CONTACT ZONE

When we come to consider the case that the sheet is supposed to have a heated contact zone, we have again as important the conditions close to the margin and those at the center, and in each case we can find relatively simple expressions for the grain, though the intermediate grain does not depend on them so simply.

First we can see that a formula which we found in the Isle Royal report will enable us readily to construct the curves of decreasing temperature, which are shown in plates 55 and 56, in the former when the contact zone supposed heated is narrow, and in the latter when it is as wide as to the distance to the center of the dike.

If v represents the temperature at a time t of a point at a distance of z from the center of the sheet, the thickness of the sheet being $2w$ with a contact zone of breadth y on either side, so that the whole zone affected or c is equal to $2w + 2y$, then—

$$(2) \qquad v = \frac{1}{2}\left(u_{w+z} + u_{w-z}\right)$$

where u_{w+z} is the temperature which would exist at the same time t after

the beginning of cooling and conditions otherwise the same in a sheet whose thickness was equal to c at a distance of $w+z$ from the margin and u_{w-z} is the temperature at a point at a distance of $w-z$ from the margin in the same sheet, or if $w-z$ becomes negative—that is, the point lies in the contact zone—we must assume

$$(3) \qquad u_{w-z} = -u_{z-w}$$

Now if we let x' be the distance of the point in the sheet with a contact zone from the margin of the sheet—that is, $x' = \left(\frac{c}{z} - z - w\right)$

$$(4) \qquad v = \frac{1}{z}\left(u_{x'+2y} + u_{x'}\right).$$

So if we take y to be $\frac{1}{24}$ of c, then for various values of x' from 0 to 11 the center we shall have as corresponding values of v respectively one-half the values of curve 2 of plate 54, values half way between curves 1 and 3, 2 and 4, 3 and 5, 4 and 6, 5 and 7, 6 and 8, 7 and 9, 8 and 10, and at the center the values of curve 11 for the same time.

Similarly if y be 6, the margin will have half the values of curve 12 and the center will have the values of curve 6 for the same times. Thus we can obtain plates 55 and 56 either graphically (very rapidly) or by taking means of appropriate rows of a table of solutions of the case where the margin is kept at a fixed temperature, a table which is given in the Isle Royal report for an initial temperature of .7854, and here for the initial temperature of 1.

We see from these plates that the temperature of the margin begins half way between the temperatures of the magma u_0, and that of the contact zone, which is taken as 0° initially. There will be a certain space of time, the longer the broader the contact zone, before it drops appreciably from this initial temperature of $u_0/2$.

Now, until the margin has thus cooled it is not hard to see that the cooling will be as though the temperature of the margin were permanently fixed. The fact that it is going to cool by and by will not make any antecedent difference.

It will be the same as the cooling of a sheet with the constant marginal temperature $u_0/2$ to be taken as 0°. The temperature of consolidation will have to be reckoned from this—that is, will be $u - u_0/2$—and the position of the point will have to be reckoned from the margin of the sheet—that is, will be $x' = x - y$. Thus representing the grain formed (under conditions of diffusivity and other constant factors represented by k, of distance from the margin by x, of temperature of crystallization

by u, of initial temperature by u_o, of thickness of effective contact zone by y, and of total thickness affected by c) in this first period by g' (k, x, u, u_o, y, c) we have

$$g'\left(k, x, u, u_o, y, c\right) = g'\left(k, x', u - \frac{u_o}{2}, \frac{u_o}{2}, 0, 2w\right). \tag{5}$$

Suppose, as Queneau* does, we let $m = \frac{x}{2a\sqrt{t}}$ and $m_o = \frac{c}{2a\sqrt{t}}$ and suppose the grain g to be $= k \frac{1}{\sqrt{D_t u}}$, then we may find the general formula

$$g = \frac{kc}{a\sqrt{u_o}} \cdot \frac{1}{m_o\sqrt{2m_o\, D_{m_o}\, u/u_o}} = \frac{kc}{a\sqrt{u_o}} \cdot \frac{x}{c} \cdot \frac{1}{m\sqrt{2m\, D_m\, u/u_o}} = \tag{6}$$

$$\frac{kc}{a\sqrt{u_o}} \cdot \frac{x}{c} \cdot \frac{1}{h\,(u/u_o)^{\frac{3}{2}}\sqrt{2}}$$

where h represents the ratio of $\sqrt{\frac{m^3\, D_m\, u/u_o}{(u/u_o)^3}}$. For quite a range of values of u/u_o h is practically constant, and it is not a function of x near the margin when $u/u_o = P_m = \frac{2}{\sqrt{\pi}} \int_o^m e^{-m^2}\, dm$. If we let m and h' stand in the same relation to x' and to $\frac{u - \frac{u_o}{2}}{\frac{u_o}{2}}$ as m and h do to x and to $\frac{u}{u_o}$, then we have

$$g' = \frac{kc}{a\sqrt{u_o}} \cdot \frac{x'}{c} \cdot \frac{1}{h'\sqrt{\left(\frac{2u}{u_o} - 1\right)^3}} \tag{7}$$

With the little table for h in case $u/u_o = Pm$, which we give, it is easy to find approximate values for the ratios of temperature of injection and consolidation, finding which we may insert in equation 7 a closer value for h, and so proceed. It is obvious that unless the consolidation temperature is very near that of injection the value of h of .8 or a little more will be a fairly close approximation.

The next stage, when simple formulæ for the grain can be obtained,

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*Loc. cit.

is when the cooling has proceeded so far that the cooling and the temperature at the margin are practically the same as that of a certain plane in a sheet whose walls are kept at a fixed temperature. Thenceforward the temperature at the margin is the same as a point at a certain fixed distance y' from a margin of a sheet whose walls are kept fixed at the initial temperature of the country rock and whose breadth is the whole breadth of the whole zone affected. The same thing is true of the cooling at the center of the sheet in the contact zone compared with the cooling at a certain distance from the margin of the same ideal cold walled sheet. From this we may derive formulæ (8):

$$(8)\begin{cases} g''\left(k, x, u, u_0, y, c\right) = g\left(k, \dfrac{c-2(y+y')}{c-2y}x' + y', u, u_0, 0, c,\right) \doteq Ax' + B = g'' \\ \text{where} \\ A = \dfrac{kc}{a\sqrt{u_0}} \cdot \dfrac{1}{c} \cdot \dfrac{c - \overline{2y+y'}}{c-2y} \cdot \dfrac{1}{h\sqrt{2(u/u_0)^3}} \quad B = \dfrac{y'}{c} \cdot \dfrac{kc}{a\sqrt{u_0}} \cdot \dfrac{1}{h\sqrt{2(u/u_0)^3}} \end{cases}$$

At the center these formulæ or formula (9) will hold:

$$(9) \qquad g'''(k, x, u, u_0, y, c) = \frac{kc}{a\sqrt{u_0}} \cdot \frac{1}{\pi\sqrt{u/u_0}} = \frac{kc}{a\pi\sqrt{u}} = E.$$

It will be observed in studying the curves of cooling (plates 55 and 56) that that of the margin very soon becomes practically coincident with one of the cooling curves of the sheet whose walls are kept at a fixed temperature (plate 54), so that thenceforward the temperature at the margin is the same as it would be at a point at a certain fixed distance y' from the margin of the cold walled sheet. The same thing is true of the cooling at the center of the sheet. This is the same as the cooling at a certain distance from the margin of the cold walled sheet whose breadth would cover the whole zone affected.

From the formulæ above given not only can the grain be roughly constructed from the data k, u, u_0, y, and c, but if from observation we can construct the curve of grain for a given mineral with such accuracy that we can locate the tangents in question we can then conversely draw inferences regarding some or all of these data. But we shall usually have to use approximate formulæ, and a glance at a few typical curves of grain will show us what inferences may be drawn without any special calculation. Plate 57 shows a number of curves of grain for different values of u/u_0 and a small contact zone. Plate 58 gives curves of grain when the contact zone is large. As the contact zone becomes smaller and smaller the curves approach those appropriate to the case when the contact belt is kept at a constant temperature.

We may make the following comments:

(1) The shape of the curves depends almost wholly on the ratio of the initial temperature to that of consolidation.

(2) Unless these temperatures are very close together the grain at the center does not vary with their ratio, but is proportional to $(kc / a\sqrt{u})$, being greater the greater the size of the sheet and the less the conductivity and temperature of consolidation.

This last condition may be more significantly worded by saying that the grain is coarser the nearer the country rock temperature is to the temperature of consolidation.

(3) The grain at the margin should be 0 if the initial temperature is more than twice the temperature of consolidation.

(4) The grain will be greater at the margin than at the center if the initial temperature is more than twice the temperature of consolidation; but if it is much more the grain will practically even throughout, as with some aplites. (Curve .40 of plate 58.)

(5) If there is a broad contact zone and the initial temperature is not far below twice the temperature of consolidation, there will be a belt of coarse grain not at but parallel to the margin. (Curve .52 of plate 58.)

(6) When the contact zone is quite small and the initial temperature below the twice the temperature of consolidation the increase of grain will at first be linear and very rapid, then linear and less rapid. This leads to a practically somewhat puzzling uncertainty. Take a straight line, such as is deduced by Queneau from his observations to be the line of grain for the Palisades augite and feldspar. Can we safely assume this to be of the type g'' or may it not be of the form g', the slight grain at the margin which it would give being due to inaccuracies of observation or little irregularities of the temperature. In my Isle Royal report I have not made allowance for this ambiguity. The conclusions drawn on page 243 are probably wrong accordingly, the ratio of the temperature of consolidation to that initially is probably too low, and the initial temperature calculated is too high.

Approximate Formulæ

Now, if we suppose that we can make certain simplifications, which can often be done, we can obtain approximate formulæ which are very easy to handle. We will assume that y is equal to y' and that the fraction $\frac{c - 2(y + y')}{c - 2y} = 1$. This we may do when the contact zone is relatively small. We will also introduce h and call $u / u_0 = f^2$. Also we call the expression $(k\,c / a\sqrt{u_0})\,K$ and we have the following formulæ:

(10) $$C = K/ch'(2\,u/u_0 - 1)^{\frac{3}{2}} = K/ch'\,(2f^2 - 1)^{\frac{3}{2}}.$$

(11) $$A = K/ch\,(u/u_0)^{\frac{3}{2}}\sqrt{2} = K/ch\,f^3\sqrt{2}.$$

(12) $$B = Ky'/ch\,(u/u_0)^{\frac{3}{2}}\sqrt{2} = Ky'/ch\,f^3\sqrt{2}.$$

(13) $$E = K/\pi\sqrt{u/u_0} = K/\pi f.$$

From 11 and 12 we can determine y', the effective contact zone, which is B/A.

(14) $$y' = \frac{B}{A}.$$

If y is less than $1/12\ c$, we may be sure that so far as the contact zone is concerned our approximate solutions are pretty close. From (11) and (13) we can find c in terms of A, E, and K—that is, we can sometimes by observation of the grain determine the thickness of the dike when it was not known. Moreover, we can find f in terms of A, E, and c, and if f^2 does not come out too near to unity we may feel that our approximate formulæ and results from them are not likely to be far out. We can also find K in terms of A, E, and c, or if we have formulæ (10) we can either check on our observations or get along without c or some other factor. From formulæ (10) and (11) we can find f in terms of C and A, although the equation is a cubic best solved by approximation. We can then find K/c.

Suppose we find a certain rate of increase of grain, the slope of a certain straight line tangent to the curve of the grain. We may not know surely whether it represents C or A. Take, for instance, Queneau's equations. They give a small value for the grain of the augite at the margin. Now, theoretically, if the slope represents C, there should be no grain at the margin, but practically there is liable to be grain at the margin according to the equation derived from our observations owing to the imperfection of the same or to some minor irregularities. We will therefore call this slope s. Now, from equations (11) and (13) we have equation

(15) $$f^2 = u/u_0 = E/.45\,hAc = E/.45\,hsc.$$

From (10) and (13) we have equation

(16) $$2f^2 = 1 + (E/.45\,h'Cc)^{\frac{2}{3}}\,(2f^2)^{\frac{1}{3}} = 1 + (E/.45\,h'sc)^{\frac{2}{3}}\,(2f^2)^{\frac{1}{3}}.$$

Thus it will be comparatively easy to obtain the alternative values of u/u_0 on the two hypotheses. Since $2u/u_0$ is always between 1 and 2 and

the cube root varies but slowly, it will be easy to insert an approximate value in (16) and obtain nearer approximations. Moreover, having found u/u_0 we can go on to find K.

$$(17)\qquad K = \pi E \sqrt{\frac{u}{u_0}} = Cch' \left(2\,u/u_0 - 1\right)^{\frac{3}{2}} = Ach\,(u/u_0)^{\frac{3}{2}}\sqrt{2}\,.$$

An interesting question is where the various tangents meet—that is, where will the zone of marginal grain become equal to that of the center. If we refer to g' and g''', we have the following formulæ :

$$(18)\qquad x'_{13} = E/c = ch'\,(2f^2 - 1)^{\frac{3}{2}}/\pi f,$$

where x'_{13} is the abscissa of the meeting point and x'_{13}/c is less than .282; and if to g'' and g''', similarly

$$(19)\qquad x'_{23} = (E - B)/A = .45\,hcf^2 - y',$$

where $(x'_{23} + y')/c$ is less than .4; and finally lines g' and g'', formulæ 10, 11, 12, will meet at a point given by

$$(20)\qquad x'_{12} = B/(C - A) = y \Big/ \frac{h}{2h'}\left(1 - \frac{1}{2f^2}\right)^{-\frac{3}{2}} - 1.$$

From formulæ (18) and (19) we shall not be able to find the width of the contact zone, but we may often be able to if we know over what range some of these formulæ are closely applicable. If, for instance, formula 10 holds at least to a value x', it may be shown that

$$(21)\qquad 2y \text{ is not less than } x'/P^{-1}(2\,u/u_0) - 1 \text{ or } 2w.$$

Also (in equation 20), if we know x_{12} $y = \left(\frac{(2 \text{ to } \infty)^{\frac{3}{2}}\,h}{2h'} - 1\right)x$

$$= \left(1.4 \text{ to } \infty\ \frac{h}{h'} - 1\right)x.$$

Eocrystals or Phenocrysts formed soon after Rest

An interesting application of the view point which we have developed may be made to the granite dike some 2,000 feet wide cut by the Wachuset aqueduct and exposed on Carvill hill, near Clinton, Massachusetts, which has been very carefully studied by W. O. Crosby,* who has kindly guided me over the ground, so that while I quote from him I am also speaking from personal observation.

*Technology Quarterly, vol. xii, no. 2, June, 1899, pp. 68 to 98.

Mr Crosby states on page 74 that

"The granite of this belt is normally very closely and profusely porphyritic, being in large part crowded with feldspar phenocrysts from 1 to 3 inches long; but toward the margins of the belt the phenocrysts become elongated" [?], "broken, and indistinct, and the porphyritic structure gradually fades out, with or without" [note well] "the development of a more or less pronounced laminated or gneissic structure."

On page 75 he says:

"Everywhere near its contact . . . the granite of this belt is non-porphyritic and distinctly gneissoid, . . . but within a few yards of the contact, as a rule, we pass gradually to the normally coarsely porphyritic granite. . . . The gneissic structure is plainly marked throughout the entire breadth of the granite, especially by the lenticular forms of the quartz and the usually parallel orientation of the great feldspar phenocrysts. Through the western middle portion of the belt the normal granitic structure is best preserved, but advancing toward the schist and more especially toward the diorite the feldspars show distortion by stretching and cracking, which increases slowly at first and then more rapidly. . . ."

This marginal gneissic structure of the granite Mr Crosby regards (page 95) as "an original structure due to the drag of the stiffly viscous granite magma along its walls during its intrusion." It may be interesting to remark that I arrived at the same conclusion from the grain study that I made, independently, though later.

Crosby gives on page 87 a detailed section of the aqueduct tunnel with the fault on the contact of the granite and schist at 758 feet, a large inclosure from 827 to 845 feet. From 845 on the laminated gneissoid structure becomes less distinct. At 900 feet, as I measured them, the large feldspar phenocrysts were about an inch long, at 1,000 feet they were about 2 inches long, and thereafter, as far as I went, nearly uniform in size. Crosby says that at 1,625 feet there is a large irregular pegmatitic development blending with the inclosing granite. Is not this due to the aqueous residue near the center of the dike? At 1,755 feet there are inclusions and other disturbances, but, says Crosby, the coarsely porphyritic, massive, and indistinctly gneissoid characters are "uninterrupted for over 1,600 feet, but east of 2,600 feet the phenomena of the western border are repeated," the contact with the diorite being at 2,690 feet.

The faults and inclosures forbid us to expect any great accuracy, and yet we may obtain some interesting results. The whole zone affected by injection can not be less than 563 meters, the least width of the granite dike, and may well be much more. The grain of the feldspar at the middle and in the belt of constant grain is about 51 millimeters, the increase from 1 inch at 900 feet to 2 inches at 1,000 will give a minimum

rate either for A or for C,* while, on the other hand, the increase of grain from the nearest possible contact from which to reckon the same (0 at 845 feet to 1 inch at 900 feet) will be a maximum. Thus A or C is more than 25.4/30,480, or 1/1,200, and is less than 25.4/16,900, or 1/670. If, suppose this to be A, and remember that there is a zone of some 1,600 feet which is of uniform grain, so that x', where the two tangents meet, is less than 30 meters and probably nearer or more than 40, we shall find that the temperature of consolidation of feldspar will be only .283, and that the zone outside of the granite at which the temperature is affected was 21 meters or less. It is hardly possible that the initial temperature of the granite should be three or four times that of the consolidation of the feldspar with no melting around the margin and so narrow a zone in which the temperature is affected. It will also imply a high degree of the fluidity of the magma, and that the difference of the temperatures initially would be large compared with the temperatures of consolidation of the feldspar and the quartz. Here are four improbabilities. Let us try the other assumption that the slope or increasing grain is to be referred to C. This implies a relatively broad contact zone, a natural supposition to make in case of granite. We shall find in this case the ratio of the temperature of consolidation to the initial temperature, .75. This, we see, brings the curve of grain into the form of the curve marked .60 in plate 5. The quartz, if formed, on the whole, later than the feldspar, will have a more uniform grain. The great coarseness of the feldspar (that is, E) is dependent upon k, $c, / a\sqrt{u}$. Now, c is fairly large, but not exceptional for granite, and it is natural to suppose that u and u_0 were not great, which would also produce a similar effect. This u_0 represents the temperature of the granite magma when it is injected above the country rock, and that it should not be great is a natural supposition for a deep-seated rock and would lead us to expect that the magma would be viscous. This is in harmony with the evidence of drag and shearing, though viscous magmas are rather characteristic of "salic" magmas.

Even with the very meager and imperfect data above given, therefore we seem justified in assuming as probable that this granite was injected under conditions such that the difference in conditions between the magma initially and the country rock was not very great; that the conditions (temperature) of the formation of the feldspar was about twice as near to the initial condition of the magma as to that of the country rock, and that under such conditions the feldspar was distinctly ahead of the quartz, at least in the beginning of its crystallization. It seems also that there was some flowage or orogenic squeezing of the magma,

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* Eqs. 10 and 11.

while it was still viscous, after the marginal zones had largely consolidated, but perhaps before the center had crystallized nearly as much.

Just to fix our ideas, and by way of illustration, if we suppose the country rock to have had a temperature of 100 degrees centigrade, and that the temperature of formation of the feldspar is 700 degrees centigrade, then the initial temperature of the magma was 900 degrees.

In Pirrson's article already referred to, in which I am in full accord, he remarks that the coarseness of grain and the developement of phenocrysts must depend on the crystallization interval—in other words, the slowness of cooling. I also agree with him that the loss of included water vapor may be important, but, as he implies, that will be a function of a loss of heat when pressure ceases to change and the eruptive or intrusive act has ceased. Whether it remains directly proportional to it remains to be seen, but all conclusions as to the belt of uniform grain will be unaffected. The same comment applies to what Pirrson says of viscosity, so far as that is directly or indirectly a function in temperature.

Another case where the same principles apply, although the result is not by any means as striking, is such a diabase dike as that of Light House point, Marquette. In a section which I measured where it is about 54 feet across the augite increased from the margin until about 5 feet in (1.622 millimeters); the average diameter of the augite was .67 millimeters, while at the center it was only a little over 1, whereas, where we take the magnetite 5 feet in, that is somewhat less than ½ a millimeter in diameter, where at the center the average dimension is .93 millimeters. The result is that the magnetite is relatively much more conspicuous at the center. The inference, confirmed by other observations, is that the magnetite was formed earlier than the augite.*

Border Phenocrysts or Oriocrystals

We now come to consider the second class of crystals to which I wish to call special attention, those which are extra large near the margin. In the only case which I have found of which I feel sure the crystals are, however, not what would ordinarily be called phenocrysts, but I take this up to show the possibility, and will then show how a slight modification of the initial condition might produce what would pass for phenocrysts.

Medford Dike, Massachusetts

This dike is very similar in general character to the Palisades trap, which has been studied by Queneau, and the Light House Point dike,

*See following paper.

which I have studied, and has been described by many writers. Their writings are cited in a recent monograph by A. W. G. Wilson, issued by the Boston Society of Natural History, so that I will proceed at once to some observations which I made on the grain at Powder House hill. Unfortunately I was unable to find the exact contact, but the first section taken was close to it, judging from appearances. Below we give the results of observations :

No	I	II	III	IV	V	VI	VII	VIII
Distance from I in millimeters	0	560	1615	2240	10000	20000	30000	40000
Grain of augite in millimeters:								
Macroscopic	.83	1.36	4.23	3.13	1.92	1.74	1.62	1.69
Microscopic	2.05	2.15	4.05	1.65	1.04	1.21	1.45	1.17

The macroscopic observations were made on the hand specimens to get a general idea of the grain, and do not pretend to be accurate. The microscopic observations are derived from the average of the dimensions at right angles of five of the larger augite grains taken in each slide. The grain of specimens II and III was subjected to special verification. Three extra observations on each specimen gave for the grain of the augite 2.47 and 3.86 millimeters respectively, so that there can be no doubt as to the existence of a belt of coarse augite near the margin.* The grain will therefore obviously have a curve of the type of .52, plate 58. The marginal grain slope C is hardly less than .0017 and the margin of the dike can hardly be more than a meter from I and is most likely considerably less. The grain in V, VI, VII, VIII is obviously practically the same, so that we have the average grain of the coarse central belt of uniform grain 1.32 millimeters. Now, whether we start from the fact that the zone of uniform grain is not less than two-thirds the breadth of the dike, after which there is an increase, or from the fact that the augite is as great as at the center within a meter or so from the margin, we shall arrive at a value of u/u_0, but little above .50.

The temperature of consolidation of the augite is therefore just a little nearer that of the injected magma than that of the country rock. In this case the augite is practically the last formed mineral and the others occur imbedded in it.

Marginal Phenocrysts

Suppose, however, the above case that the augite, instead of being among the latest formed minerals, was among the earlier formed. It

*Mr L. C. Graton told me that near Roberts station, north of Georgian bay, he had seen dikes with a coarse grained seam near the margin.

might obviously be very much more conspicuous and the same time automorphic near the margin. Suppose, for instance, that in a granite the initial temperature was such that $u_o/2$ was within the range of formation of the feldspar, while the quartz formation was at a considerably lower temperature. The feldspar would be conspicuously coarser near the margin, while the quartz might not vary much from center to margin, having a curve or grain something like that numbered .40 of plate 58.

Mathematical Summary

We may briefly summarize the results of the mathematical investigations as follows:

In an injected sheet of uniform temperature and conductivity whose walls are kept at a fixed temperature the temperature may be expressed in one of two ways, the former most applicable at the early stages of cooling, the latter in the latter stages of cooling.

$$\frac{u}{u_o} = P_m - \left(P_{m_0+m} - P_{m_0-m}\right) + \left(P_{2\,m_0+m} - P_{2\,m_0-m}\right) - \dots .$$

$$\frac{\pi}{4}\,\frac{u}{u_o} = q \sin \pi\, x/c + \frac{q^9}{3} \sin 3\,\pi\, x/c + \frac{q^{25}}{5} \sin 5\,\pi\, x/c.$$

$$\text{Where } m = x/2a\sqrt{t} \text{ and } m_o = c/2a\sqrt{t} \text{ and } q = \varepsilon^{-(\pi/m_o)^2}$$

$$\text{and (see page 406) } P_m = \frac{2}{\sqrt{\pi}}\int_o^m e^{-m^2}\,dm.$$

From these we may derive two formulæ for the grain approximately, one of which represents a tangent to the grain at the margin, if we assume a certain part of it—namely, h not to depend on x. We give above a table for h. The other represents the grain at the middle and a tangent to the grain at the middle, provided the consolidation takes place in the latter stage of cooling. In case we do not assume that the walls are kept at a fixed temperature, we may find the temperature as functions of those of a dike whose walls are kept at a fixed temperature by the following formula:

$$v = \left(u_{x'} + u_{x'+2y}\right).$$

And for the grain we can derive a formula which is applicable at the margin, another applicable at the center, and another applicable between in case the contact zone is not large, which will represent three tangents to the real curve of the grain as follows:

$$y = g' = Cx' \text{ where } C = K / ch' \, (2\,u/u_0 - 1)^{\frac{3}{2}}$$

$$y = g'' = Ax' + B = \frac{K}{ch\,(u/u_0)^{\frac{3}{2}}\sqrt{2}}\left(\frac{c - 2\,(y + y')}{c - 2y}\,x' + y'\right)$$

$$y = g''' = E = K/\pi\sqrt{u/u_0} = \frac{kc}{a\,\pi\sqrt{u}} \text{ where } K = \frac{kc}{a\sqrt{u_0}}.$$

If from an observed curve of the grain we can determine these tangents approximately and the points of intersection, we can find a number of data as to initial conditions by the following formulæ :

$$\frac{u}{u_0} = f^2 = E/.45\,hAc \qquad 2\,f^2 = 1 + (E/.45\,h'Cc)^{\frac{2}{3}}\,(2\,f^2)^{\frac{1}{3}}$$

$$= 1 + (E/.45\,h'Cc)^{\frac{2}{3}}\left(1 + (E/.45\,hCc)^{\frac{2}{3}}\,(1 + 4c)^{\frac{1}{3}}\right)^{\frac{1}{3}}$$

$$K = \pi\,Ef = Ach\,(u/u_0)^{\frac{3}{2}}\sqrt{2} = Cch'\left(\frac{2u}{u_0} - 1\right)^{\frac{3}{2}}$$

$$x'_{13} = \frac{E}{C} = ch'\,(2\,u/u_0 - 1)^{\frac{3}{2}}/\pi\sqrt{u/u_0} \quad \text{and is} < .282.$$

$$x'_{23} = (E - B)/A = .45\,hc\,f^2 - y' \quad \text{and } \frac{x'_{23} + y'}{c} \text{ is } < .4$$

$$x'_{12} = B/(C - A) = y/\frac{h}{2h'}\left(1 - \frac{1}{2\,u/u_0}\right)^{-\frac{3}{2}} - 1 \qquad \frac{x'}{y} \text{ is between 0 and}$$

$$\frac{h\sqrt{2}}{h'} - 1.$$

We also give as useful tables in this connection a table of the probability integral derived from Johnson :

$$u/u_0 = P_m = \frac{2}{\sqrt{\pi}}\int_0^m e^{-m^2}\,dm.$$

We also give a table giving u/u_0 for various values of q. With these in hand, it is not difficult to solve questions that may arise, if the necessary facts have been observed.

The observations to be made in the field, if possible, are as follows :

The size of the sheet or dike ;

Indications as to whether the contact zone is broad or narrow and more or less altered ;

The distances of a series of sections from the margin of the dike or sheet. One should be at the margin and others within a very few inches. Another group should be from a quarter to half way from margin to center, one or two nearer the center, and one as near the center as possible.

The observations to be made in the laboratory include the size of the different constituents in the different specimens, the average linear dimension of fair grains; but this should not be divorced from a study of signs of corrosion, transportations while being formed, floating in the magma, and definite orientation relative to the margin.

The results which may be looked for are:

An idea of the size of the sheet and the contact zone, if these could not be observed in the field;

An idea of the stage of development of the magma at the time of intrusion;

And, from the known limits of temperature or conditions of formation of the constituent minerals, an idea of the relative temperatures of the intruded and intruding rocks.

Table of u/u_0 when $u_0 = 1$ for various values of x (distance from margin) and q; $\left(-\text{dec log } q = 1.0715\ m_0^{-2}\right)$.

1.00	.99	.98	.97	.96	.95	.94	.93	.92	.91	.90	.80	.70	.60	.50	.40	.30	.20	.10	$q = 0.00$	$24\frac{x}{c}$
1.0000	0.6444	0.4852	0.4040	0.3613	0.3172	0.2835	0.2688	0.2519	0.2368	0.2241	0.1553	0.1229	0.1013	0.0834	0.0665	0.0499	0.0332	0.0117	0	1
1.0000	.9353	.8058	.7111	.6404	.5862	.5309	.4964	.4897	.4533	.4217	.3048	.2372	.2007	.1653	.1319	.0966	.0659	.0329	0	2
1.0000	.9968	.9493	.8102	.8306	.7810	.7357	.6973	.6635	.6341	.6077	.4433	.3569	.2975	.2443	.1950	.1428	.0974	.0487	0	3
1.0000	1.0000	.9909	.9660	.9331	.8977	.8632	.8306	.8002	.7719	.7459	.5667	.4521	.3861	.3190	.2547	.1910	.1273	.0637	0	4
1.0000	1.0000	.9999	.9919	.9779	.9590	.9372	.9193	.8910	.8682	.8460	.6882	.5584	.4690	.3883	.3100	.2325	.1550	.0775	0	5
1.0000	1.0000	1.0000	.9973	.9940	.9858	.9744	.9607	.9455	.9294	.9129	.7598	.6422	.5308	.4508	.3602	.2701	.1759	.0900	0	6
1.0000	1.0000	1.0000	.9997	.9986	.9959	.9909	.9838	.9751	.9651	.9541	.8289	.7135	.6077	.5054	.4040	.3030	.1974	.1010	0	7
1.0000	1.0000	1.0000	1.0000	.9996	.9989	.9971	.9940	.9897	.9841	.9766	.8813	.7718	.6616	.5513	.4410	.3308	.2204	.1102	0	8
1.0000	1.0000	1.0000	1.0000	1.0000	.9997	.9993	.9980	.9961	.9933	.9897	.9189	.8168	.7041	.5878	.4704	.3528	.2352	.1179	0	9
1.0000	1.0000	1.0000	1.0000	1.0000	.9999	.9996	.9994	.9985	.9974	.9956	.9437	.8488	.7349	.6141	.4919	.3689	.2459	.1229	0	10
1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	.9999	.9998	.9995	.9990	.9981	.9580	.8678	.7534	.6306	.5048	.3787	.2524	.1262	0	11
1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	.9999	.9997	.9994	.9987	.9626	.8742	.7597	.6357	.5091	.3819	.2546	.1273	0	12

Values of the probability integral, Pm: sometimes $= u / u_0$.

M.	0	Difference.	1	Difference.	2	Difference.	3	Difference.	4	Difference.	5	Difference.	6	Difference.	7	Difference.	8	Difference.	9
0.0	0.0000	.113	0.0113	.113	0.0226	.112	0.0338	.113	0.0451	.113	0.0564	.112	0.0676	.113	0.0789	.112	0.0901	.112	0.1013
0.1	.1125	.111	.1236	.112	.1348	.111	.1459	.110	.1569	.111	.1680	.110	.1790	.110	.1900	.109	.2009	.109	.2118
0.2	.2227	.108	.2335	.108	.2443	.107	.2550	.107	.2657	.106	.2763	.106	.2869	.105	.2974	.105	.3079	.104	.3183
0.3	.3286	.103	.3389	.102	.3491	.102	.3593	.101	.3694	.100	.3794	.099	.3893	.099	.3992	.098	.4090	.097	.4187
0.4	.4284	.096	.4380	.095	.4475	.094	.4569	.093	.4662	.093	.4755	.092	.4847	.090	.4937	.090	.5027	.090	.5117
0.5	.5205	.087	.5292	.087	.5379	.086	.5465	.084	.5549	.084	.5633	.083	.5716	.082	.5798	.081	.5879	.080	.5959
0.6	.6039	.078	.6117	.077	.6194	.076	.6270	.076	.6346	.076	.6420	.074	.6494	.072	.6566	.072	.6638	.070	.6708
0.7	.6778	.069	.6847	.067	.6914	.067	.6981	.066	.7047	.065	.7112	.063	.7175	.063	.7238	.062	.7300	.061	.7361
0.8	.7421	.059	.7480	.058	.7538	.057	.7595	.056	.7651	.056	.7707	.054	.7761	.053	.7814	.053	.7867	.051	.7918
0.9	.7969	.050	.8019	.049	.8068	.048	.8116	.047	.8163	.046	.8209	.045	.8254	.045	.8299	.043	.8342	.043	.8385
1.0	.8427	.041	.8468	.040	.8508	.040	.8548	.038	.8586	.038	.8624	.037	.8661	.037	.8698	.035	.8733	.035	.8768
1.1	.8802	.033	.8835	.033	.8868	.032	.8900	.031	.8931	.030	.8961	.030	.8991	.029	.9020	.028	.9048	.028	.9076
1.2	.9103	.027	.9130	.025	.9155	.026	.9181	.024	.9205	.024	.9229	.023	.9252	.023	.9275	.022	.9297	.022	.9319
1.3	.9340	.021	.9361	.020	.9381	.019	.9400	.019	.9419	.019	.9438	.018	.9456	.017	.9473	.017	.9490	.017	.9507
1.4	.9523	.016	.9539	.015	.9554	.015	.9569	.014	.9583	.014	.9597	.014	.9611	.013	.9624	.013	.9637	.012	.9649
1.5	.9661	.012	.9673	.011	.9684	.011	.9695	.011	.9706	.010	.9716	.010	.9726	.010	.9736	.009	.9745	.010	.9755
1.6	.9763	.009	.9772	.008	.9780	.010	.9788	.008	.9796	.008	.9804	.007	.9811	.007	.9818	.007	.9825	.007	.9832
1.7	.9838	.006	.9844	.006	.9850	.006	.9856	.005	.9861	.006	.9867	.005	.9872	.005	.9877	.005	.9882	.004	.9886
1.8	.9891	.004	.9895	.004	.9899	.004	.9903	.004	.9907	.004	.9911	.004	.9915	.003	.9918	.004	.9922	.003	.9925
1.9	.9928	.003	.9931	.003	.9934	.003	.9937	.002	.9939	.003	.9942	.002	.9944	.003	.9947	.002	.9949	.002	.9951
2.0	.9953	.002	.9955	.002	.9957	.002	.9959	.002	.9961	.002	.9963	.001	.9964	.002	.9966	.001	.9967	.002	.9969
2.1	.9970	.002	.9972	.001	.9973	.001	.9974	.001	.9975	.001	.9976	.001	.9977	.002	.9979	.001	.9980	....	.9980
2.2	.9981	.001	.9982	.001	.9983	.001	.9984	.001	.9985	....	.9985	.001	.9986	.001	.9987	....	.9987	.001	.9988
2.3	.9989	....	.9989	.001	.9990	....	.9990	....	.9991	....	.9991	.001	.9992	....	.9992	....	.9992	.001	.9993
2.4	.9993	....	.9993	.001	.9994	....	.9994	.000	.9994	.001	.9995	....	.9995	....	.9995	....	.9995	.001	.9996
2.5	.9996	....	.9996	....	.9996	....	.9997	....	.9997	....	.9997	....	.9997	....	.9997	....	.9997	.011	.9998
2.6	.9998	....	.9998	....	.9998	....	.9998	....	.9998	....	.9998	....	.9998	....	.9998	....	.9998	.001	.9999
2.7	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
2.8	....	....	....	....	....	....	....	....	....	....	....	....	.9999	.001	....	....	....	....	....

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 14, PP. 407-420, PL. 59 OCTOBER 19, 1903

ORDOVICIAN SECTION NEAR BELLEFONTE, PENNSYLVANIA*

BY GEORGE LUCIUS COLLIE

(*Presented before the Society January 2, 1903*)

CONTENTS

Introduction

During the summer of 1902 the writer made a collection of Ordovician fossils in the neighborhood of Bellefonte, Pennsylvania, for purposes of future comparison with faunas of like age in Wisconsin.

Several interesting features were brought out during the study of the Pennsylvania material, and a preliminary account of them is presented in this paper.

Bellefonte is the county seat of Center county, the geographical center of the state, as the name indicates. The town lies in Nittany valley, a denuded anticline, which affords exceptionally good exposures of the

*The writer wishes to acknowledge his great indebtedness to Dr C. E. Beecher, of New Haven, and Messrs E. O. Ulrich and Charles Schuchert, of Washington, for aid in the determination of species and for many helpful suggestions.

Ordovician rocks. The particular section described in this paper extends from the tollgate one mile south of Bellefonte to the entrance of Milesburg gap, north of the town. The best exposures are at the city laundry, near the Nittany Valley Iron Company's furnace in Bellefonte, and in the northern environs of the town along the Milesburg turnpike.

According to Rogers:

"The main anticline of Nittany valley is by far the greatest of the Alleghany group. Its length is 130 miles, its width from 15 to 18 miles, and the actual vertical height, if restored, is as much as 20,000 feet." *

Nittany valley is bounded on the northwest by Bald Eagle ridge, on the southeast by the ridge of Nittany mountain.

The Ordovician rocks reach a great thickness in the valley. D'Invilliers reports at least 6,000 feet of Ordovician limestones without, however, bringing the bottom beds to the surface.†

In some portions of Nittany valley, both to the east and to the west of Bellefonte, the axial beds are sandstones which form the so-called "sand barrens." ‡ In the Bellefonte section no sandstone appears, except local lenses at the base of the limestone series.

The anticline in which the section described is located has gentle southeast dips, while the northwest dips are steep; consequently the anticline is unsymmetrical. Its crest lies close to the northwest border of the valley.

The Ordovician beds disappear beneath Bald Eagle mountain and do not outcrop again until the Mohawk valley is reached, 100 miles to the north.

Position and Thickness of the Rocks

At the crest of the anticline, 1 mile south of Bellefonte, the dips either way are gentle, not exceeding 8 degrees. On approaching the mountains the dips gradually increase until at the contact of the Trenton limestone and the Utica shale, near Bald Eagle ridge, the dip is 65 degrees. The average direction of dip in the Bellefonte section is north 30 degrees west, although there are numerous local deviations from that direction. The average dip of the Utica shale is 70 degrees north 30 degrees west; that of the Lorraine shale is between 70 degrees and 90 degrees north 30 degrees west. The Lorraine shale is frequently vertical or even overturned, but ordinarily it is less than 90 degrees. The limestones and the Utica shale are situated in the valley; the Lorraine shale forms the base of the mountains.

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* H. D. Rogers: Geol. Pennsylvania, vol. i, pt. i, p. 467.

† E. V. d'Invilliers: Pennsylvania Second Geol. Survey, vol. T. 4, p. 301.

‡ E. V. d'Invilliers: Pennsylvania Second Geol. Survey, vol. T. 4, p. 30.

The thickness of the Ordovician limestones, measured from the lowest exposure in the section to the base of the Utica shale, is 5,752 feet according to the author's measurements. The total thickness of the shales between the top of the Trenton and the base of the Oneida is 1,000 feet. Though there is a decided lithological and faunal break between the Utica and the Lorraine shales, it is difficult in this case to define the exact boundaries of the two formations. The interval of 350 feet between the known Utica and Lorraine is occupied by a shaly formation apparently devoid of fossils. At present, therefore, it is impracticable to classify this intervening formation. Lithologically the doubtful formation is more closely allied to the Utica than to the Lorraine. If the known range of *Triarthrus becki* is used as the determining factor in estimating the thickness of the Utica, it does not exceed a thickness of 300 feet. If, however, the middle non-fossiliferous formation be added to it on account of its lithological resemblances, then the Utica reaches a thickness of 650 feet. On this basis of division the Lorraine shale is 350 feet thick.

Character of the Rocks

IN GENERAL

Extended descriptions of the rocks in the Bellefonte region have been given by various investigators connected with the different Pennsylvania surveys.

Rogers speaks of the enormous thickness of the Auroral magnesian limestone. He divides the calcareous rocks of the valley into two general classes, which he describes in the following terms:

> "One of these is a rock of rather dull gray aspect and a crystalline or granular structure; this variety is decidedly ferruginous. The other formation is a remarkably smooth and fine grained rock of very pale blue color. It is very uniform in texture and consists apparently of excessively comminuted particles. It is highly magnesian, the weathered surface being coated with a white crust. The total thickness of the formation visible in Nittany valley in the vicinity of Bellefonte considerably exceeds 5,000 feet." *

Rogers again divided the limestones into two groups based on the presence or absence of fossils. The lower or unfossiliferous group is 4,800 feet thick; the upper or fossiliferous horizon is 600 feet thick. He regarded the upper group as the equivalent of the Birdseye and Black River formations of New York. He assigned a thickness of 150 feet to the Birdseye and 450 feet to the Black River. Rogers evidently inferred the presence of Birdseye limestone on lithological grounds, since he cites no list of distinctive Birdseye fossils.

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* H. D. Rogers: Geol. of Pennsylvania, vol. i, part i, p. 470.

D'Invilliers* gives a detailed cross-section of Nittany valley and a careful description of the geological structures to be found there.

In somewhat less detail Lesley † gives cross-sections and descriptions of the rocks in Nittany valley, with especial reference to the iron-bearing limestone.

Lesley differs from Rogers somewhat in his interpretation of the age of the Magnesian limestone series. He does not consider it to be wholly Calciferous, but assigns the upper portion, with a thickness of 1,000 or 1,200 feet, to the Chazy.‡ He states that the Calciferous II *a* is almost non-fossiliferous, the Chazy II *b* is slightly fossiliferous, and the Trenton II *c* is abundantly fossiliferous.§

Ewing || gives added descriptions of the rocks, and also a list of the fossils known to him. According to his statement, few fossils are found in the lower part of number II, and those found are mainly fragmentary and indistinct.

In the catalog of the Survey museum, volume 0.3, Mr C. E. Hall has amplified the list of fossils given by Ewing.

In this paper the author adopts the term Beekmantown ¶ in place of Calciferous or Magnesian limestone; the term is much more suitable than the old names and ought to replace them.

The writer has found the Beekmantown to be fossiliferous, and has discovered three distinct fossiliferous horizons in the formation. There is apparently no true Chazy present, but rocks containing the fauna of the Stones River group,** which includes the Birdseye zone of New York as its upper member, follow immediately on the Beekmantown. These in turn are followed by the Black River and Trenton groups, above which follow in order the Utica and Lorraine shales.

The chief lithologic features of the rocks are set forth in the following table, together with the thickness of each subdivision:

GROUP I.—BEEKMANTOWN STAGE

	Feet
1. Dark, compact, thick bedded limestone, frequently oolitic in structure, containing lenses of white silicious sandstone..........	150
2. Variegated, dark and light gray limestone, breaking with conchoidal fracture..........	35

* Pennsylvania Second Geol. Survey, vol. T. 4, p. 28.

† Pennsylvania Geol. Survey, 1892, Summary Final Report, vol. i, p. 365.

‡ Pennsylvania Geol. Survey, 1892, Summary Final Report, vol. i, p. 517.

§ Pennsylvania Geol. Survey, 1892, Summary Final Report, vol. i, p. 501.

|| Pennsylvania Second Geol. Survey, vol. T. 4, p. 427.

¶ Clark and Schuchert, Science, vol. 10, pp. 874–878.

** The Stones River group was originally proposed by Safford in 1851 (Am. Jour. Sci., 2d series, vol. xii, p. 352), and in 1897 was resurrected and redefined by Winchell and Ulrich in Introduction to Minn. Geol. Survey, vol. 3, part II, p. xc.

	Feet
3. Dark, crystalline limestones frequently brecciated, alternating with thick bedded gray limestones; thin sheets of calcite in the bedding planes or in masses and veins; containing *Ophileta complanata*. Horizon A-1	215
4. Gray, crystalline limestone	48
5. Compact dolomitic gray limestone mottled with dark blotches	36
6. Soft, porous white limestone	18
7. Thin, laminated dark limestones containing brecciated fragments of black limestone	220
8. Compact, splintery black limestones alternating with light gray oolitic limestones and drab colored dolomitic limestones, containing *Ribeiria calcifera* and *Asaphus marginalis*. Horizon A-2	322
9. Thick bedded crystalline and compact dark limestones	624
10. Gray crystalline limestone	132
11. Gray crystalline limestone alternating with bands of dark crystalline limestone	313
12. Massive beds of light gray crystalline limestone	198
13. Thick bedded crystalline limestones of dark color, stained with iron oxide, containing *Bathyurus amplimarginatus*. Horizon A-3	157
14. Compact yellowish gray and drab dolomitic limestone, frequently thin bedded and laminated, alternating with numerous thin beds of dark limestone, weathering to a light gray color. Nodules of chert occur frequently, and in such occurrences the rock tends to be arenaceous	2,335
Total thickness of the Beekmantown	4,803

GROUP II.—STONES RIVER STAGE

1. Carbonaceous crystalline black limestone alternating with light gray limestone, containing *Leperditia fabulites*, *Protorhyncha ridleyana*, etcetera. Horizons A-4, A-5, A-6	253
Total thickness of the Stones River group	253

GROUP III.—BLACK RIVER STAGE

1. Black, fetid, shaly limestone alternating with thick beds of gray limestone, the latter containing veins of calcite; contains *Strophomena filitexta*, *Maclurea bigsbyi*, *Receptaculites occidentalis*, *Rhinidictya mutabilis*, etcetera. Horizon A-7	93
Total thickness of the Black River formation	93

GROUP IV.—TRENTON STAGE

1. Compact lusterless shaly black limestone, rarely crystalline, containing *Rafinesquina alternata*. Horizons A-8, A-9	187
2. Thick bedded gray limestones, usually unfossiliferous. Horizon A-10	124
3. Thin bed of fissile black shale, containing lenses of fossiliferous limestone. Horizon A-11	2.5
4. Crystalline gray limestone, containing *Illænus crassicauda*, *Isotelus platycephalus*, etcetera. Horizon A-12	43.

	Feet
5. Black slaty shale, with a few thin lenses of limestone, containing *Plectambonites sericeus*, etcetera. Horizon A–13	3.5
6. Light gray limestone filled with veins and nodules of calcite, containing *Plectambonites sericeus*, etcetera. Horizon A–14	56
7. Dark slaty shale containing *Protowarthia cancellata*, *Salpingostoma expansa*, etcetera. Horizon A–15	6
8. Shaly black limestones alternating with thin beds of crystalline gray limestone, containing *Trematis terminalis*, etcetera. Horizon A–16	181
Total thickness of the Trenton formation	603
Total thickness of the Ordovician limestones	5,752

GROUP V.—UTICA STAGE

1. Laminated dark-colored fissile shales, alternating with a few thin beds of limestone near the base of the formation; contains *Triarthrus becki*, etcetera. Horizon B–1	90
2. Soft red and brown shales containing nodules of iron pyrites, at the top alternating with thin beds of sandstone containing *Triarthrus becki*. Horizon B–1	210
3. Soft ferruginous shales alternating with fissile black and brown shales, containing oval nodules of iron pyrites unfossiliferous	250
4. Brown, red, and green shales, quite soft and much broken by cross-jointing; the shales contain numerous nodules of iron pyrites, apparently unfossiliferous	100
Total thickness of the Utica formation	650

GROUP VI.—LORRAINE STAGE

1. Soft gray and brown shales alternating with black slaty shales; in the upper portion of the formation thin beds of sandstone and ferruginous limestone (rotten-stone) occur at frequent intervals; contains *Cyrtolites ornatus*, *Byssonychia cincinnatiensis*, etcetera. Horizon B–2.	350
Total thickness of the Utica and Lorraine shales	1,000
Total thickness of the Ordovician rocks in the Bellefonte section	6,752

The Faunas and Their Relationships

Horizon A–1, the lowest fossiliferous horizon, occurs in a dark, iron-stained, oolitic limestone 400 feet above the lowest exposure of rock in the section. The fossil-bearing horizon is only a few inches in thickness; the fossils are obscure and usually in a worn and comminuted condition, all of which renders their identification difficult. The only recognizable species are *Ophileta complanata* Vanuxem and a small Ophileta similar in general appearance, probably *O. levata* Vanuxem. The facies of this fauna clearly indicates the Beekmantown age of this horizon.

Between horizon A–1 and A–2 there is an interval of 537 feet of limestone, which appears to be completely unfossiliferous.

Horizon A–2 is 937 feet above the base of the section. In it are found great numbers of an Asaphoid trilobite and broken fragments of several varieties of the genus Eccyliomphalus. The identifiable species are *Asaphus marginalis* Hall, *Ribeiria calcifera* Billings, *R. parva* sp. nov.; a spirally coiled Eccyliomphalus, similar in appearance to *E. distans* Billings, but smaller; *Ophileta uniangulata* Hall. There are a number of other species represented, especially of Eccyliomphalus, but in such a fragmentary condition that trustworthy identification is difficult. The fossils range through a vertical height of 90 feet; the *Asaphus marginalis*, which is exceedingly abundant, though represented chiefly by pygidia, occurs within the limits of a few feet at the base of the horizon in an oolitic limestone. The Ribeirias are associated with the Asaphus. The Eccyliomphalus occurs above these forms, chiefly at the top of the horizon. The fauna shows decisively the Beekmantown age of this second horizon.

Immediately succeeding A–2 there are 1,499 feet of unfossiliferous limestone before the third horizon, A–3, is reached, or 2,536 feet above the base of the section. There is an abundant fauna present in horizon A–3, ranging through 150 feet in vertical height. The principal fossils found at this horizon are *Bathyurus amplimarginatus* Billings, *Maclurea affinis* Billings, *Liospira strigata*, sp. nov., *Protowarthia rossi*, sp. nov., and *Dalmanella subæquata gibbosa* (Billings). The genera and species of this horizon are strikingly similar to those described by Billings from the Calciferous of the Mingan islands, gulf of Saint Lawrence. So marked is this resemblance of faunas that there can be little question that they represent identical horizons. The Mingan Islands horizon has always been regarded by the Canadian geologists as Upper Calciferous. This view accords well with the fact that the Pennsylvania horizon is the uppermost fossiliferous horizon found in the Beekmantown. Provisionally at least, horizon A–3 may be referred to the Upper Beekmantown.

All of this great series of limestones described above, with a thickness of 4,803 feet, is to be regarded as Beekmantown. As already indicated, it is possible to divide the formation into three divisions: a lower, characterized by *Ophileta complanata*; a middle, marked by *Asaphus marginalis*, and an upper, distinguished chiefly by *Bathyurus amplimarginatus*.

Horizon A–4 is separated from A–3 by 2,335 feet of unfossiliferous dolomitic limestone. Some of the Pennsylvania geologists, notably H. D. Rogers,* have referred to this intervening formation as a coralline limestone in part. The writer has found but few traces of fossils in these

* H. D. Rogers: Geol. of Pennsylvania, vol. i, part i, p. 471.

rocks and those so obscure as to be worthless for purposes of identification. The first fossiliferous horizon known above the dolomitic limestone probably represents the Ridley limestone of the Stones River group, which includes the formations between the Beekmantown and the Black river. The two lower divisions of the Stones river—that is, Murfreesboro and Pierce limestones—do not seem to be present. The overlying Mohawkian * group includes the Black River and the Trenton formations.

The thickness of the Stones River and Mohawkian rocks is 949 feet, distributed as follows: Stones River, 253 feet; Black River, 93 feet, and Trenton, 603 feet. The fossils found in these formations usually occur in thin zones. They are not distributed generally through the rock, and this is the case especially in the impure shaly limestones.

The principal fossils found in horizon A–4 are *Bathyurus extans* Hall, *Leperditia fabulites* Conrad, *Strophomena filitexta* (Hall), and *Protorhyncha ridleyana* (Safford).

Horizon A–5 may be regarded as the possible equivalent of the Lebanon limestones as described by Safford. The principal fossils occurring here are *Leperditia fabulites* and *Lophospira milleri* (Hall).

In horizon A–6 the only form found in abundance is *Strophomena filitexta* (Hall). Certain zones are filled with it. It will be noted that this horizon contains no fossils typical of the Stones River group. It might as well be classed with the Black River formation or be regarded as a transition zone between the Stones River and the Black River. On litholoical grounds, the author prefers to class it with the Stones River group rather than with the succeeding formation. Horizons A–4 to A–6, inclusive, are therefore grouped together under the head of Stones River, a group that seems to be in geographical distribution, thickness, and paleontological interest nearly or quite equal to the Trenton limestone itself.†

In horizon A–7 are found the extensive quarries of the region, which has greatly facilitated the collecting of fossils in spite of the fact that the rocks as a whole are quite unfossiliferous.

The faunas of this horizon show that it belongs to the Black River formation, though in the upper portion basal Trenton forms begin to appear. The principal fossils found are as follows: *Trinucleus concentricus* Eaton, *Ceraurus pleurexanthemus* Green, *Isotelus platycephalus* Stokes, *Pterygometopus callicephalus* (Hall), *Calymmene callicephala* Green, *Illænus crassicauda* Wahlenberg, *Tetranota obsoleta* Ulrich, *Maclurea bigsbyi* Hall,

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*As originally defined by Clarke and Schuchert (Science, vol. 10, pp. 874–878), the Mohawkian includes the Birdseye or Lowville limestone, but Winchell and Ulrich regard the Birdseye as the top member of the Stones River group (Geol. Survey of Minnesota, vol. iii, part ii, p. xc).

† Winchell and Ulrich: Geol. Survey of Minnesota, vol. iii, part ii, p. xc.

Strophomena filitexta, *Parastrophia schofieldii* Winchell and Schuchert, *Triplecia* sp. nov., having the general appearance of *Platystrophia; Hebertella bellirugosa* (Conrad), *Platystrophia biforata* (Schlotheim), *Streptelasma corniculum* Hall, *Receptaculites occidentalis* Salter, *Prasopora simulatrix orientalis* Ulrich, *Hemiphragma ottawaense* Foord, *Rhinidictya mutabilis* Ulrich. Hemiphragma is exceedingly abundant in the upper part of this horizon and is its most characteristic fossil.

Horizon A–8 may be regarded as the basal zone of the Trenton. It is marked by the abundant remains of a homalonotoid trilobite, *Brongniartia trentonensis* (Simpson). Other fossils occurring in this zone are *Trinucleus concentricus*, *Isotelus platycephalus*, *Cytoceras camurum* Hall, *Protowarthia tenuissima* sp. nov., *Rafinesquina alternata* (Emmons), *Dalmanella testudinaria* (Dalman), *Orthis tricenaria* Conrad.

In horizon A–9 trilobites are especially abundant. They include *Isotelus platycephalus*, *Pterygometopus callicephalus*, *Illænus crassicauda*, and *Encrinus tuberculosus* sp. nov. Other fossils are *Tetranata obsoleta*, *Orthis tricenaria*, *Plectambonites sericeus* (Sowerby), *Rafinesquina alternata*, *Parastrophia scofieldii*, *Dinorthis subquadrata* (Hall), *Plectorthis plicatella* (Hall), *Cornulites flexuosus* Hall, *Hemiphragma ottawaense*.

Few varieties of fossils are found in horizon A–10. *Plectambonites sericeus* occurs in abundance, and also *Rafinesquina alternata*. *Lingula riciniformis* Hall also occurs.

The rocks in horizon A–11 are shales chiefly and nearly unfossiliferous. *Plectambonites sericeus* is the only form noticed.

In horizon A–12 an abundance of gasteropods is the most notable feature. The principal forms represented are *Tetranota bidorsata* (Hall), *Hormotoma bellicincta* (Hall), *Liospira americana* (Billings), *Murchisonia tricarinata* Hall, *Lophospira bicincta* (Hall), *Subulites canadensis* Ulrich, *Conradella grandis* Ulrich, *Eccyliomphalus undulatus* (Hall), *Salpingostoma canadensis* (Billings), *Salpingostoma buelli* (Whitfield), *Fusispira angusta* Ulrich. Other fossils found are *Ceraurus pleurexanthemus*, *Isotelus platycephalus*, *Illænus crassicauda*, *Orthoceras strigatum* Hall, *O. textile* Hall, *Triptoceras hastatum* (Billings), *Orthis tricenaria*, *Dinorthis pectinella* (Emmons), *Plectorthis plicatella*, *Rafinesquina alternata*, *Plectambonites sericeus*, *Hemiphragma ottawaense*.

Horizon A–13 resembles A–11 in all respects. It is a thin bed of shale, in which *Plectambonites sericeus* occurs abundantly, especially in the limestone lenses, which are found in the shale.

In horizon A–14 *Plectambonites sericeus* and *Rafinesquina alternata* occur in great numbers. *Plectorthis plicatella* and *Dalmanella testudinaria* are found occasionally.

Horizon A–15 is especially marked by the abundance of *Salpingostoma*

expansa (Hall) and *Protowarthia bilobatus* (Sowerby). Other types occurring here are *Protowarthia cancellata* (Hall), *Trochonema ambigua* Hall, *Liospira progne* (Billings), *Eotomaria dryope* (Billings), *Vanuxemia hayniana* Safford, *V. abrupta* Ulrich, *Cyrtodonta grandis*, Ulrich, and *Rafinesquina camerata* (Conrad).

In horizon A–16 the limestones are very shaly, increasingly so toward the Utica horizon. The fossils are confined mainly to the beds of purer limestone, which occur at intervals in the shaly limestone. *Trinucleus concentricus* and *Prasopora Simulatrix orientalis*, however, occur in vast numbers in the shaly portion of the rock. The most characteristic fossils found are a number of Lingulas, as follows: *L. obtusa* Hall, *L. elongata* Hall, *L. curta* Conrad; also *Trematis terminalis* Emmons. In addition, the following fossils occur: *Tetradella subquadrata* Ulrich, *Isotelus platycephalus*, *Calymmene callicephala*, *Hormotoma gracilis* (Hall), *Conularia trentonensis* Hall, *Lophospira perangulata* (Hall), *Whitella subtruncata* (Hall), *Dalmanella testudinaria*, *Platystrophia biforata*, *Strophomena filitexta*.

Horizons A–8 to A–16, inclusive, carry Trenton faunas and may be referred to that formation, though the total thickness, 603 feet, is much greater than the Trenton ordinarily reaches. At the base of the Trenton proper the most typical and common fossil is *Orthis tricenaria;* in the middle horizons *Plectambonites sericeus* becomes the most characteristic type; in the upper Trenton Plectambonites disappears for the most part and *Dalmanella testudinaria* becomes the most marked form. Dalmanella occurs in very great numbers in the uppermost horizon of the Trenton. The order of occurrence noted above accords well with observations made by Weller in the Trenton of New Jersey.*

It will be seen from the above enumeration of fossils that the faunas are very closely related to those of the same age both in New York and in the northwest. Almost the only exception to this statement is the occurrence of Brongniartia in horizon A–8.

Utica and Lorraine Shales

Horizon B–1 contains a few fragments of *Dalmanella testudinaria* and *Isotelus platycephalus*, but the most characteristic fossil is *Triarthrus becki* Green. This form is seen in great numbers at the base of the Utica, but more sparingly above. Its total range appears to be about 300 feet in vertical height.

Horizon B–2 includes the series of shales belonging to the Lorraine formation. The rocks are not well exposed in the neighborhood of Bellefonte, and the descriptions here given are taken from a study of the exposure at Matternville, a few miles north of Bellefonte.

*Geol. Survey of New Jersey Paleontology, vol. iii, p. 37.

Fossils are found mainly in the soft ferruginous limestones and shaly sandstones which are interstratified with the shales proper throughout the whole horizon. The fossils though abundant are poorly preserved as a whole; the chief forms found are as follows: *Calymmene callicephala*, *Cyrtolites ornatus* Conrad, *Lophospira acuminata* Ulrich, *Protowarthia planodorsata* Ulrich, *Trochonema nitidum* Ulrich, *Hormotoma gracilis* (Hall), *Archinacella patelliformis* (Hall), *Modiolopsis modiolaris* Conrad, *Ctenodonta pectuncaloides* Hall, *Orthodesma nasutum* (Hall), *Cleidophorus planulatus* (Conrad), *Ctenodonta levata* (Hall), *Lyrodesma poststriatum* (Emmons), *Byssonychia cincinnatiensis* Miller, *Orthorhynchula linneyi* (James), *Rafinesquina squamula* James, *Dalmanella testudinaria multisecta* Meek, *Zygospira modesta* Hall, *Platystrophia lynx* (Eichwald), *Arthropora schafferi* Meek.

The Utica and Lorraine shales, like the Mohawkian, contain faunas very similar to those of New York. The lithological features of the rocks are also strikingly similar, indicating that the conditions of deposition in the two regions were much alike.

Summary

This paper presents an account of a section of Ordovician rocks at Bellefonte, Center county, Pennsylvania. The rocks are well exposed on each side of an unsymmetrical anticline, which forms Nittany valley, between the isoclinal Bald Eagle ridge and the synclinal Nittany ridge.

The Ordovician rocks exposed in this section are 6,752 feet thick; 5,752 feet are limestones and 1,000 are shales.

The rocks dip toward Bald Eagle at angles varying from 8 to 90 degrees, the dip increasing as the mountain is approached. The average direction of the dip is north 30 degrees west.

There are four fossiliferous horizons in the limestones and two in the shales. Each of these horizons is separated from its successor by unfossiliferous beds, usually of great thickness.

The lowest horizons, A–1 to A–3, inclusive, contain a Beekmantown fauna. The total thickness of the Beekmantown rocks is 4,803 feet.

Horizons A–4 to A–6, inclusive, contain a fauna which may be regarded as of Stones River age.

The remainder of the limestones are Mohawkian, both the Black River formation and the Trenton being represented. The author has found no evidence of the presence of either true Chazy or Birdseye fossils.

The Stones River group is 253 feet in thickness, the Black River is 93 feet, and the Trenton is 603 feet thick.

Following the limestones is a series of shales, the lowest horizon in the shales containing fossils of Utica age; the thickness of the Utica is 650 feet.

The Lorraine shales occupy the upper 350 feet of the shale series. In the Lorraine there are a number of fossiliferous beds which contain fossils similar to those of like age in New York.

Description of New Species

BRONGNIARTIA TRENTONENSIS (SIMPSON) *

Plate 59, figure 1, thorax and pygidium ; figure 2, cranium

The author of the above species figured but did not describe a trilobite which he found in Huntingdon county, Pennsylvania, under the name stated above. It is now necessary to restrict Simpson's species, though his specific name should be retained.

Salter has used the sub-generic term Brongniartia for Ordovician types related to Homalonotus, and his usage is adopted here, and the name *Brongniartia trentonensis* applied to this particular trilobite. The writer has figured the species anew, and the following is a description of it:

Entire animal 8 centimeters long; somewhat elongate and narrowing behind ; distinctly trilobed, test punctate.

Cranidium, irregularly trapezoid in form ; anterior margin gently convex, anterior border broad, concave; posterior border nearly straight, with distinct occipital groove.

Glabella, defined somewhat imperfectly by dorsal furrows, subquadrate, smooth, convex; the median area strongly convex. Free cheeks not observed.

Thorax, with 11 (?) segments, axis one-third the whole width.

Pygidium, eight pleural annulations, triangulur, length two-thirds the greatest width; posterior rounded with narrow flat margin; axis convex, well defined by dorsal furrows, tapering rapidly, rounded at the posterior end, which terminates just within the margin ; 11 annulations.

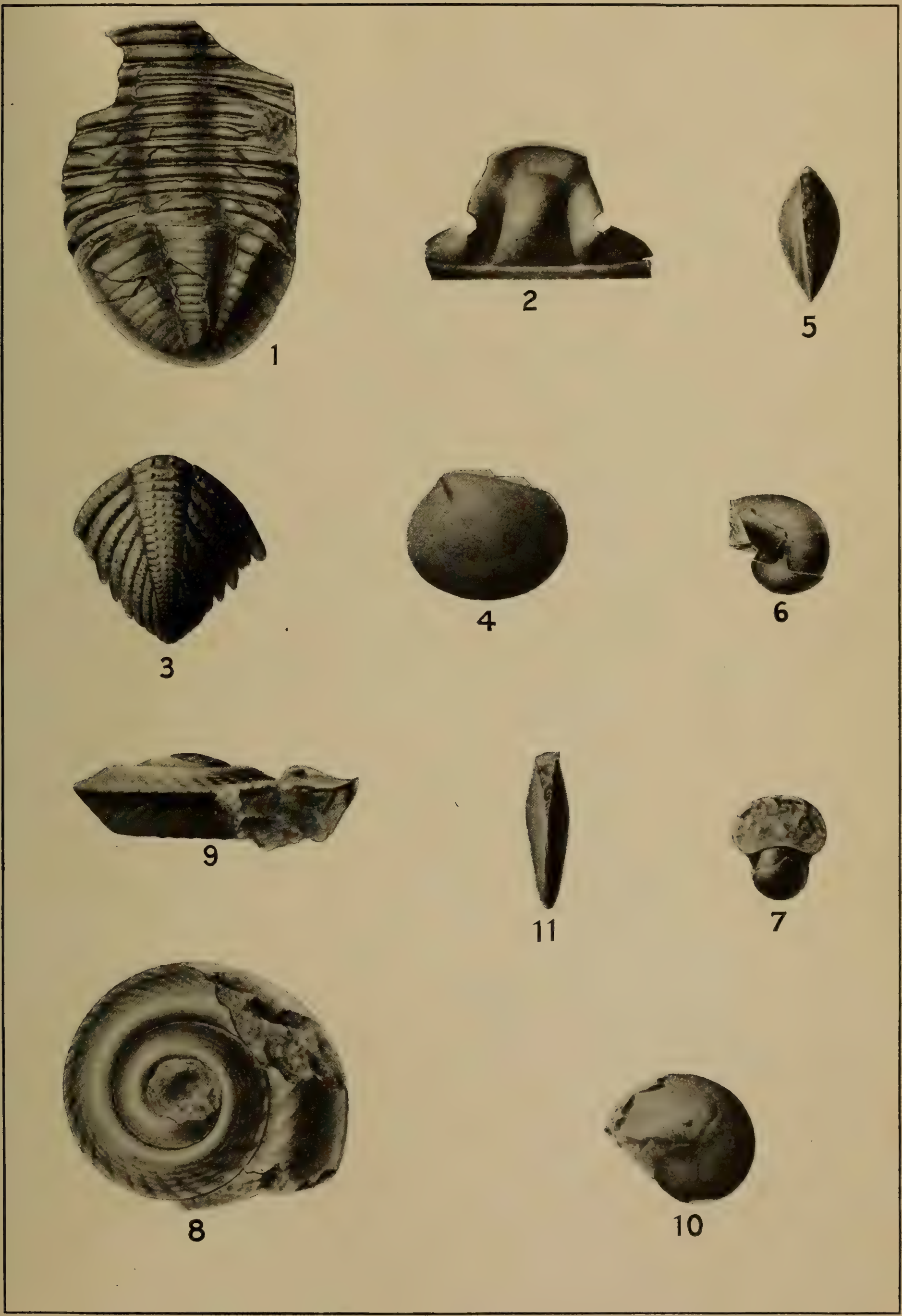
Locality and formation, Bellefonte, Pennsylvania, in the lower portion of the Trenton group. Collected by G. L. Collie.

ENCRINURUS TUBERCULOSIS SP. NOV.

Plate 59, figure 3, pygidium × 2 diameters

Pygidium, sub-pentagonal in outline, elongated, conical and convex axis; 25 annulations, normally three tubercles on each, but not well defined toward the posterior. Side lobes with eight moderately broad, slightly convex ribs, the last pair commencing at the eighteenth axial annulation and extending backward nearly parallel with the axis ; the succeeding three pairs are about parallel with the posterior pair, the

* *Homalonotus trentonensis* Simpson, Proc. Am. Phil. Soc., vol. 16 (new series), 1890, p. 460, figure 31.



NEW FOSSILS FROM BELLEFONTE, PENNSYLVANIA

anterior four pairs diverge slightly, but the posterior half of each becomes nearly parallel to the rest of the series. Ribs are somewhat elevated at their proximal extremities on the dorsal furrow; they end in free and somewhat blunted tips. Ribs covered with tubercles, especially along the edges. Length, 15 millimeters; greatest width the same; greatest width of axis, 6 millimeters at its anterior.

This species differs from other described species of Encrinurus in possessing a greater number of pygidial annulations and in the thoroughly tuberculated character of the pygidium.

Locality and formation, Bellefonte, Pennsylvania, in the lower Trenton horizon. Collected by G. L. Collie.

RIBEIRIA PARVA SP. NOV.

Plate 59, figures 4 and 5, lateral and posterior views × 3 diameters

Carapace small, ovate, compressed, 7 millimeters long, 5 millimeters in height, 3 millimeters thick. Straight dorsal margin, with muscular impressions faintly visible, bilaterally symmetrical; antero-dorsal extremity notched; the notch 1 millimeter long, extending toward the center of the shell; anterior rounded, posterior somewhat narrower than the anterior, not so well rounded, somewhat appressed. The posterior end slightly gaping; surface apparently smooth.

This species resembles *R. nuculitiformis* Cleland, but differs in having no fold or sinus. It is much smaller than *R. calcifera* Billings.

Locality and formation, Bellefonte, Pennsylvania, in the middle Beekmantown horizon. Collected by G. L. Collie.

LIOSPIRA STRIGATA SP. NOV.

Plate 59, figures 8 and 9, lateral and profile views

Shell lenticular, spire depressed, conical, whorls four to five; 4 centimeters in greatest diameter, convex above, passing into concave just within the periphery. Edge slightly raised, forming a sharply defined border; below concave beneath the border, then convex; umbilicus nearly one-half the diameter, its edge subangular; slope of the whorls within gently inclined toward the center; height little more than one-third the diameter. Surface of the upper side marked by broad, somewhat sigmoid elevations or ridges, with sharply defined depressions between; both ridges and depressions sweep backward somewhat strongly on approaching the periphery; similar but fainter ridges below; concentric lines parallel to the periphery visible on well preserved portions of the shell.

This form is very similar in general appearance to *Pleurotomaria canadensis* Billings, but differs from that species in the surface ornamentation. The sigmoid ridges are much better defined in the Penn-

sylvania species, while the concentric lines are better shown in the Canadian species. The Canadian species also show stronger concavity beneath the peripheral edge.

Locality and formation, Bellefonte, Pennsylvania, in the upper Beekmantown horizon. Collected by G. L. Collie.

PROTOWARTHIA TENUISSIMA SP. NOV.

Plate 59, figures 10 and 11, lateral and dorsal views

Lenticular, greatly compressed; acute dorsum; vertical diameter, 23 millimeters; greatest width just above the umbilicus, 6 millimeters. From the umbilicus the surface ascends by a gentle convex slope to the acute dorsal edge.

Umbilicus small, scarcely 2 millimeters across, rounded on the edge. The aperture is compressed ovate, indented two-fifths of its height by the penultimate whorl. Narrow emargination in the outer lip, which extends back about one-fifth of the circumference of the outer whorl. Surface smooth, except for a few growth lines, which begin at the umbilicus and follow the edge of the aperture, bending back around the emargination.

The specimens of this species that have been collected all show the extremely compressed character which gives the name to the species. At first it was believed that the individuals were compressed specimens of *P. cancellata*, but quite a number of specimens collected invariably show the same attenuated condition without evidence of the distortion which usually appears in crushed fossils. It is now believed that the compression is a specific character. In other respects the new species resembles *P. cancellata*, though there is no evidence of a cancellated surface.

Locality and formation, Bellefonte, Pennsylvania, in the lower portion of the Trenton formation. Collected by G. L. Collie.

PROTOWARTHIA ROSSI SP. NOV.

Plate 59, figures 6 and 7, lateral and apertural views × 2 diameters

Shell small and globose, rarely exceeding 8 millimeters in diameter, the width of the aperture equaling the height; whorls broad, inflated, and strongly convex; umbilicus about one-fourth the diameter of the shell, subacute on the edge. No emargination visible, aperture subquadrate, expanded laterally, indented one-third its height by the preceding whorl. Surface smooth, without apparent growth lines.

A small and primitive type of Protowarthia. It differs from *P. bilobatus*, which it most resembles, in being very much smaller and in possessing no emargination.

Locality and formation, Bellefonte, Pennsylvania, in the upper Beekmantown group. Collected by G. L. Collie.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 14, PP. 421-494, PLS. 60-63 DECEMBER 7, 1903

GENESIS OF THE AMPHIBOLE SCHISTS AND SERPENTINES OF MANHATTAN ISLAND, NEW YORK

BY ALEXIS A. JULIEN

(*Presented before the Society January 2, 1903*)

CONTENTS

Introduction

The common distribution of hornblende schists of undetermined origin, exactly or essentially like those of Manhattan island, along the whole Appalachian belt, in the Adirondack region of New York, throughout the crystalline rocks of Canada and the Northwest, as well as in Europe, has led me into a rather full discussion of the genesis of our local rock, in the hope that it may satisfy a more general interest. Although nearly twenty years have elapsed since the careful investigation of similar schists in Maryland, we are still in need of "additional light upon one of the much-mooted questions of Archean geology, namely, the origin of lenticular beds of hornblende rocks so often interbedded in the old gneisses."* A majority of the outcrops of this rock on Manhattan island have been covered by buildings, but many of the finest exposures (at least thirty-five) still remain open in street cut-

* G. H. Williams: Preliminary notice of the gabbros and associated hornblende rocks in the vicinity of Baltimore. Johns Hopkins Univ. Circ., no. 30 (1884).

tings and parks, and their varied character and easy access make this island, at present, a specially interesting field for study of this question.

Manhattan Series of Schists

Through the investigations of S. Akerly (1820), L. D. Gale (1839), W. W. Mather (1843), I. Cozzens (1843), R. P. Stevens (1865), J. D. Dana (1880–1881), J. F. Kemp (1887), L. P. Gratacap (1887), F. J. H. Merrill (1880–1896), D. H. Newland (1901), etcetera, the schists which make up Manhattan island and Westchester county, New York, which adjoins it on the north, have been assigned to the following four classes, stated from above downward:

Micaceous gneisses, fine grained, gray, biotitic, in large part pegmatitic ("Manhattan schist" or "Hudson schist" of Merrill), make up the mass of the island. In them occur thin intercalations, characteristic but in small amount, of biotite-muscovite schists of high luster, rich in quartz, with a little feldspar, cyanite, sillimanite, fibrolite, garnet, apatite, and staurolite, ; also amphibole rocks and serpentine. The thickness of the stratum has been estimated to exceed 1,000 feet.

Dolomitic granular limestone ("Inwood limestone" or "Stockbridge dolomite" of Merrill), rich in phlogopite and tremolite, with diopside, black mica, black and brown tourmaline, rutile, serpentine, etcetera. Its individual beds are thin, in one case 150 feet, alternating with micaceous gneiss. Thickness estimated from 600 to 800 feet.

White quartzite, massive to granular ("Lowerre" or "Poughquag" quartzite of Merrill); entirely wanting on the island, while in the vicinity it rarely exceeds from 12 inches to 2 feet in thickness, though infrequently it reaches 5 to 10 feet.

Laminated quartzitic gneiss, light gray, biotitic ("Fordham gneiss" of Merrill), often pegmatitic, which consists of granular quartz (about two-thirds, by Dana's estimate), with micas, feldspars, apatite, zircon, titanite, and occasionally magnetite and garnet. Thin intercalations occur of lenses of mica schist, micaceous gneiss, white quartzite, pegmatite, and black hornblende schist. In vicinity to the overlying limestone it has been found calciferous. Thickness estimated as at least 200 feet.

Underlying the above series a red gneissoid granite ("Yonkers gneiss" of Merrill) makes its appearance at many points. It is made up of quartz, reddish orthoclase, a little plagioclase and biotite. Sometimes this passes into fine granular or micaceous aplite, with muscovite or hydromica, garnet, and tourmaline. It rises as intrusive bosses into the quartzitic gneiss at Yonkers and at Union Corners, Westchester county, New York, into the micaceous gneiss of Manhattan island near West

Fifty-fifth street and Tenth avenue, and probably underneath the Battery, at the southern end of the island. On the east shore of Staten island it apparently underlies the serpentine. Apophyses of pegmatite and granite, in the form of dikes, sometimes 10 feet or more in width, penetrate abundantly upward through all the foregoing strata on Manhattan island, and in less number throughout Westchester county. An eruptive boss of subordinate character seems to be represented by the granite-diorite exposures at Harrison, Rye, and on Long Island sound between Portchester and Greenwich, Westchester county, as well as near Ravenswood, on Long island, and in the adjoining part of the bed of East river.

Evidences of Sedimentary Origin

In regard to many of these schists the following characteristics have been generally accepted as evidences of their sedimentary origin:

Granular and often loose sandy texture, prevalent in the quartzitic layers of the schists and gneisses and in the quartzites, suggestive of imperfectly altered clastic rocks, "underdone," as Dana described it. The particles of quartz and feldspar are generally angular, as if from crushing, but the smaller quartz granules may be rounded.

Marked alternation of thin layers of sandy gneiss and mica schist, the one or the other predominating in the gneisses below or above the limestone. The three materials offer a strong correspondence to altered layers of quartzose sandstone, sometimes argillaceous—of shale—and of more or less impure magnesian limestones. The thin layers of hornblende schist, in Dana's opinion, resemble original layers of highly ferruginous magnesian shales.

A schistose structure, so characterized by the regularity of the above-stated alternations as to imply its general relation to true bedding by sedimentation rather than to foliation by shearing and dynamic metamorphism during the folding of the strata; in some cases, however, only evidence of the latter agency remains.

These characteristics are best preserved in the Fordham gneiss, as shown in the fine section at One hundred and fifty-third street and Seventh avenue.

Stages of Metamorphism

Without considering for the present the basic schists and limestone, four stages are, in my opinion, plainly indicated in the alteration of the acid or silicious schists below and above the limestone.

The first was concerned in the early consolidation of the sediments.

followed progressively by their crystalline alteration, with development of certain new minerals—biotite, albite and staurolite.

Then ensued the general impregnation of all the layers with pegmatitic material, mainly quartz, orthoclase, oligoclase, and muscovite in numberless "augen," lenses, and parallel seams a few inches in thickness, which often make up one-quarter to one-third of the present constitution of the gneiss; more or less apatite, pyrrhotite and black tourmaline also become apparent in these seams. These two stages marked the progress of static metamorphism.

Next came the intrusion of a series of pegmatite dikes, cutting each other in succession, and all, so far as yet known, intersecting the pegmatite lenses of the preceding generation. With these orogenic movements seem to have been connected, with extensive folding, crumpling, and faulting of all the beds of gneiss, schist and limestone, a further increase of crystalline structure. and development from micas and feldspars of another group of minerals requiring conditions of high temperature, such as muscovite, sillimanite, fibrolite, cyanite, and tourmaline. The amount of shearing thus produced during dynamic metamorphism varied in diffferent parts, being limited in degree toward the southern end of the island, there apparently reaching only to a further stretching and thinning of the layers, resulting in several systems of joints and a slaty foliation, generally coincident with and rarely obliterating the original bedding structure. An index of this limitation in the latest period is shown in the pegmatite veins and dike intrusions, many of which (probably of the earlier series) show more or less crushing, even to the condition of schistose aplite, with development of cross-cleavage and abundance of mica, but rarely to separation and isolation as lenses rolled out within the schists.

Finally, down to the present period, ensued the oxidation, hydration, and partial leaching out of the less stable constituents of the schists by meteoric waters, with partial decomposition of the amphibole into hydrous forms of tremolite and asbestus, serpentine, ophicalcite, talc, and chlorite; of the feldspar and micas into chlorite and margarodite; of the feldspars into iron oxides, kaolin and zeolites, and of the pyrites into ferric hydrate, alums, and sulphur. All these products have been recognized on Manhattan island.

Constitution of the Micaceous Gneiss

In regard to the micaceous gneiss in the series previously referred to (page 423), a detailed description has been published* on a specimen

* J. P. Iddings: Bull. U. S. Geol. Survey, no. 150, 1898, p. 332.

of "schistose biotite-gneiss" from West One hundred and twenty-fifth street, near Riverside drive. The specimen exhibited somewhat of a *flaser* structure,

"caused by flakes of mica grouped in lines curving about larger crystals of feldspar and quartz. It was made up of biotite, quartz, and feldspar, all allotriomorphic, with a small amount of muscovite, apatite, and zircon. The quartz grains are irregular, but the smaller are often rounded. The feldspar is chiefly oligoclase, with a little orthoclase."

It is added,

"As the proportion of feldspar grows less, the rock approaches a gneissic mica schist."

A good exposure of this rock remains near Columbia University, at West One hundred and eighteenth to One hundred and nineteenth street, on Morningside avenue west. I am indebted to Professor J. F. Kemp for the opportunity to present the following analysis (I) of a specimen, made for him in duplicate by Dr C. H. Jouët, of this university. To it may be added an analysis (II) of a specimen of the same gneiss, selected for its fine grain and uniformity in texture and mineral composition, from the corner of East Fifty-second street and First avenue.* The analyst points out its approximate identity with the composition (III) of a quartzose mica schist from Tagilsk, Ural,† to indicate its probable derivation from alteration of a clay slate.

	I*a*.	I*b*.	I.	II.	III.
SiO_2	64.11	63.86	63.98	57.20	56.99
TiO_2	None.	....	None.	....	.91
Al_2O_3	17.45	17.49	17.47	19.51	18.98
FeO	6.54	6.39	6.46	....	....
Fe_2O_3	....	....	....	9.52	9.02
MnO	Trace.	....	Trace.	....	....
CaO	2.85	2.88	2 86	5.73	4.90
MgO	1.87	1.93	1.90	4.40	.75
K_2O	2.84	2.87	2.85	.28	3.00
Na_2O	2.25	2.62	2.44	2.13	2.59
Ignition loss	.71	....	.71‡	.48	2.48
Fe	....	....	....	.59	....
S	....	....	....	.67	....
			98.67	100.51	99.62

Under the microscope the thin-section is found to consist mainly of a mosaic of closely fitted grains of colorless quartz and feldspar, to an

* P. Schweitzer: American Chemist, vol. iv, 1874, p. 443, and vol. vi, 1876, p. 457.

† Kjerulf: Bischoff, El. Chem. and Phys. Geol., vol. iii, 1859, p. 344.

‡ CO_2 undetermined.

amount estimated at about 65 per cent of the volume of the rock. Of these, the quartz grains, amounting to 40 per cent of the rock, are angular and clear, inclosing a few plates of hematite, biotite, brown zircon, needles of fibrolite, and sheets of minute fluid cavities. No clastic forms or evidences of secondary enlargement were distinguished. The feldspar commonly displays polysynthetic twinning after the albite and sometimes the pericline law. Wavy extinction rarely occurs.

A few small grains of orthoclase also are found. The schist plane of the rock is strongly marked by parallel disposal of the longer axes of the grains of quartz and feldspar, and still more strongly by the plates of the other minerals. Biotite occurs, to the amount of about 18 per cent, in reddish brown plates, with the usual strong absorption and pleochroism, the latter rarely blue to red. Muscovite, to about 7 per cent, is generally inclosed within the biotite in colorless plates, which sometimes reveal an obscure fine lineation on the plane of basal sections. Sillimanite occurs in a few fragmentary, colorless plates, with cross-partings, high relief, and parallel extinction. Some show incipient alteration by variation in their bright interference colors. Fibrolite is also common in fibrous bundles intermixed with finely granular quartz. Garnet is distributed in pale reddish dodecahedra, mostly six-sided in cross-section. None display zonal structure, but in many irregular cloudy bands (strain borders) occur along the margin, which are found to be anisotrope between the cross nicols, while the center and greater part of the crystal remains dark. A little zircon occurs, imbedded in the quartz and muscovite, as minute brownish crystals of high relief and strong double refraction, and sometimes in radiating groups near the edges of the mica scales. A few irregular particles, shining plates and elongated scales of bluish black opaque hematite are also present.

Amphibole Schists

MODE OF OCCURRENCE

These occur intercalated among all the gneisses of the island, and, though often found in proximity to the limestone, are never inclosed within it nor in contact. Besides these, some observers have referred to the occurrence of pyroxenic schists, concerning which little information is on record.

VARIETIES

The following varieties are commonly distributed:

Fine-grained quartz diorite schist, and hornblende schist, passing into massive hornblendite, into biotite schist, or becoming more or less epidotic and thus altered into epidosite.

Fine-grained dioritic gneiss and hornblende gneiss, passing into biotitic gneiss.

Massive amphibolite, actinolite and tremolite rock and schist, ophicalcite and serpentine.

PYROXENIC ROCKS

I have not found a published description of pyroxenic rocks on this island by any observer. The earliest statement seems to have been that of Mather * that "augite rocks have been found at a few localities," who further mentions, under the head of "greenstone" in Putnam and Westchester counties:

"In some places it has the aspect of compact trap, like basalt, but more frequently the hornblende predominates and gives its character to the rock. . . . Many of the masses classed with this rock would be classed with sienite but for the fineness of the grain, being of about the texture of a sandstone, composed of black hornblende, with grains of white and gray feldspar."

I am indebted to Dr J. J. Friedrich of this city, who has made collections of our local rocks, for the following notes concerning localities: At East Ninety-fifth and Ninety-sixth streets, between Third and Lexington avenues, pyroxenic rocks in great abundance, in an extensive excavation, associated with chlorite schist containing pyrrhotite and pyrite. Other localities occurred from Ninety-fifth to One hundred and second street, between Third aud Fifth avenues, and less commonly east of Third avenue, with distinct evidences of the process of serpentinization.

Dr Anthony Woodward, of the American Museum of Natural History in New York city, an active collector of our rocks, has informed me of a similar locality at West One hundred and tenth street, west of Ninth avenue. There is also the latest statement † of Mr F. J. H. Merrill of the general view:

"*Basic dikes.*—Intercalated with and injected into the Hudson schist and also the Fordham gneiss, we find at a great number of localities on Manhattan island and in Westchester county hornblendic and augitic bands and lenses of limited thickness, usually only a few feet. In composition and structure these rocks resemble diorites and diabases, and their general characters suggest that they were originally eruptive rocks, though at present they are in a foliated condition."

No pyroxenic rocks, however, were found by Dana or by myself at any localities on the island, nor is there a single specimen of these in the public collections in this city, though many of dioritic and hornblendic gneiss and schist from the above-stated localities; nor in over fifty thin-

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* Nat. Hist. N. Y., part IV (1843), pp. 531-532.

† U. S. Geol. Survey, Geol. Atlas, New York city folio, no. 83, 1902, p. 3; also N. Y. State Mus. Rep. L, 1896, pp. 23, 28, 31, etcetera.


N
Harlem River
Speedway
Dyckman St.
193 st.
190 st.
186 st.
185 st.
10 Av
Spuyten Duyvil Creek
Prescott Ave.
Fort Wash" Ave.

sections of these schists which have been prepared have I been able to detect any remnant of a pyroxene. At least there appears to be insufficient evidence as to the identification of any of our rocks as pyroxenic.

DISTRIBUTION OF AMPHIBOLE ROCKS

These schists have been observed only on the northern part of the island, the greater part of whose surface, shown on the map (plate 60), is occupied by bared gneisses in beds tilted up almost everywhere at very high angles, with a general strike of about north 28° east. On this map the outcrops marked with an asterisk (*) are those which are now covered up through the growth of the city—most of them on the east side of the island—but it is shown that a great number still remain open to observation and may be easily visited by the geologist interested in this subject. Some are likely to remain always exposed, particularly those in Central, Riverside, and Morningside parks and the Speedway. It will also be shown that even a far wider distribution of altered schist is suggested by the numerous exposures of biotitic schist and gneiss. To assure oneself of this relationship, a study of the two rocks in the outcrops from West One hundred and seventeenth to One hundred and twenty-second streets would be profitable.

A linear arrangement of many exposures along the strike is apparent, but these were in most cases found to be interrupted, without connection in the interspaces.

Diorite Schist and Hornblende Schist

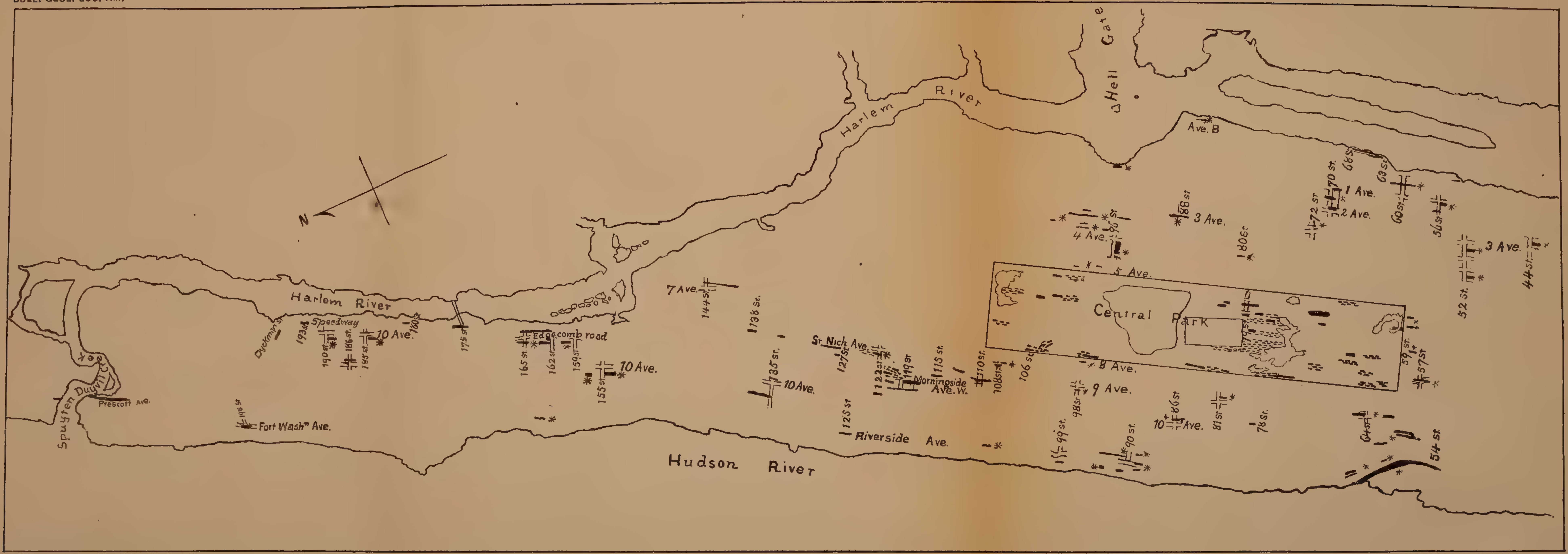
OCCURRENCE AND RELATIVE ABUNDANCE

These schists far exceed all other amphibole rocks in abundant and wide distribution on the island and call for special description. They were early recognized by Cozzens,* who defined some of their principal outcrops. They occur in the gneisses mostly as rather thin seams or lenses, from a few inches to 2 or 3 feet in thickness. On the sides of street cuttings their thinned out margins may often be traced out in establishment of a universally lenticular form. In places they may reach 20 feet or more in thickness, but then generally become quartzose and gneissoid—dioritic or hornblende gneiss—and more or less biotitic, so passing into black biotite gneiss, in which hornblende may be abundant, sparingly distributed, or entirely absent.

STRUCTURE VARIATIONS

In structure these diorite and hornblende schists, as well as their related gneisses, described further on, display two seemingly contra-

* A geological history of Manhattan or New York island, 1843, pp. 12, 15.



MAP OF PORTION OF MANHATTAN ISLAND

Showing outcrops of hornblende schist (black lines) and derivative biotitic gneiss (broken lines)

sections of these schists which have been prepared have I been able to detect any remnant of a pyroxene. At least there appears to be insufficient evidence as to the identification of any of our rocks as pyroxenic.

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* A geological history of Manhattan or New York island, 1843, pp. 12, 15.

dictory features, testifying at once both to extreme plasticity and extreme rigidity in comparison with the inclosing gneisses.

First, plication and corrugation of layers. The evidence of extreme plasticity in this rock, during the general folding and kneading to which the strata of the island have been subjected, is very markedly and frequently shown, not only by numerous folds, zigzag crumpling and distortion of the beds, but by corrugation of the layers, even down to thinnest laminæ. Thus hornblendic beds may often be distinguished at a distance, in outcrops or in section along street cuttings, both by contrast of their black color, laminated texture, and sharp margins and by their wavy folds or convolutions, as at the outcrop near West One hundred and nineteenth street (plate 61). On closer approach the laminæ may be found characterized by minute corrugations, three or more to the centimeter—very beautiful on cross-section, where thin alternations of quartz and epidote occur, as at the West One hundred and thirty-fifth street outcrop. Such distortion of folds sometimes reaches to the degree of pinching out into isolated, almost cylindrical, corrugated masses, whose extremities may appear in cross-section like the ends of columns. These may lie separated in long fluted rolls, whose ends bear a rude resemblance to sections of petrified trees, as, for example, at West One hundred and eighth street and Ninth avenue. This comparison, I find, has been anticipated sixty years ago by that of Dr L. D. Gale in regard to similar structure in hornblende gneiss at about Eightieth street on Fourth avenue:

> "Columnar gneiss is seen in many places on the island, but in none more conspicuous than at the south entrance to the tunnel. The columnar structure of gneiss only occurs where the mica is replaced by hornblende. There is not the appearance of crystallization, as in basalt and greenstone, but the fragments have the appearance of old logs, or like the half or quarter of a log, as if split and quartered by art."

He further refers to the "columnar structure" in the hornblende gneiss at Seventh avenue, south of McCombs bridge on the Harlem river.* Similar remarkable flexures and isolated rolls have been described and figured by Dana from outcrops on the north side of West One hundred and tenth street between Ninth and Tenth avenues (which is still to be seen at northwest corner of One hundred and tenth street and Morningside avenue west) and at West One hundred and thirty-third to One hundred and thirty-eighth street between Tenth and Eleventh avenues.

* Mather, op. cit., pp. 593, 599.

Second, fracture and faulting. Evidences of extreme rigidity and brittleness are also often shown in the same beds in which crumpling and corrugation are prominent. These are crossed, often abundantly, by seams or veins of gray or white quartz or of pegmatitic material, which run usually parallel to each other and at right angles to the foliation of the schist. Yet they are confined to these thin beds of hornblendic rock and are thus distinguished from the main quartz and pegmatite veins which intersect all the schists of the island. Such fractures plainly testify that the hornblendic beds have lain as rigid masses during movements of the inclosing gneiss and have yielded only by rupture along cross-planes.

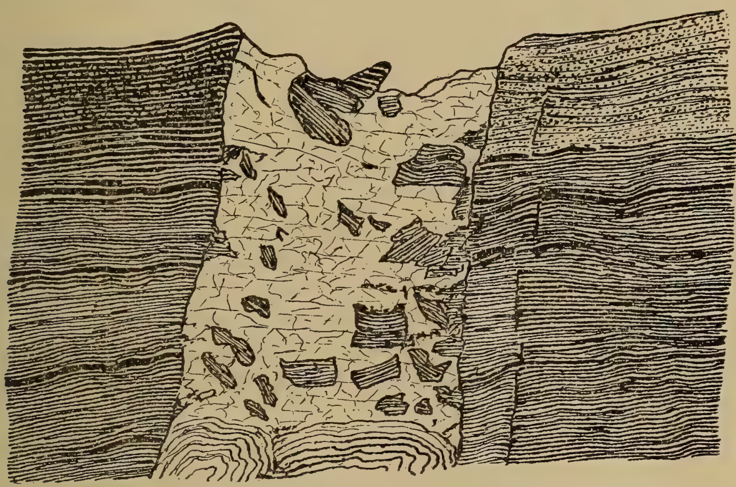

FIGURE 1.—*Fault Breccia in Quartz Vein, two feet wide, in Quartz-diorite Schist.*
Locality, West One hundred and thirty-eighth street and Saint Nicholas avenue.

An excellent example still remains open to examination on the west side of Saint Nicholas avenue, about West One hundred and thirty-eighth street. A nearly vertical sheet of diorite gneiss, partly epidotic, 3 to 4 feet in thickness, forms a wall along the sidewalk for a distance of more than 20 yards in the direction of the strike, north 21 degrees east.* Abundant cross-seams of quartz vary in thickness from 2 inches up to 2 feet. By two of these the sheet has been disjointed, and the surrounding micaceous gneiss is sometimes forced deeply into or even quite through the old fracture. One such fault-vein, 2 feet wide, is filled by a friction breccia, made up of angular fragments of the hornblendic rock, inclosed in brownish white quartz (figure 1), the walls of the fracture lined by

* True bearing, all in this paper having been corrected for magnetic variation.

hackly projections of the torn rock along both sides, as if they had been wrenched apart and rubbed together.

At other localities, as, for example, at the huge bed on Spuyten Duyvil creek, portions of the hornblendic rock are traversed by innumerable veinlets of quartz or pegmatite, indicating a shattered and even brecciated mass.

MACROSCOPIC DESCRIPTION OF HORNBLENDE SCHIST

The following is an abstract of a published description* of a hornblende schist from West One hundred and twenty-fifth street, between Claremont and Riverside avenues: Rather massive crystalline schist, greenish black, with tendency to cleave in parallel plates. In thin-section it is found to consist of dark green hornblende, with subordinate amounts of feldspar, quartz, magnetite, biotite, apatite, and a little zircon and pyrite, besides some secondary minerals in places—muscovite, epidote, or zoisite. The lamination is produced by a somewhat parallel arrangement of the stout crystals of hornblende and by streaks of the other constituents in smaller grains.

Hornblende is strongly green in thin-section, with tinge of brown and with pronounced pleochroism, the variation being from green through brownish green to light brown. Many individuals exhibit no cleavage. Extinction angle low. Twinning seldom observed. The substance of the hornblende very pure, with inclusions of occasional zircons in rounded crystals and considerable magnetite, besides feldspar, quartz, and biotite.

Feldspar in irregular grains, mostly plagioclase; some extinction angles suggest andesine labradorite; lamellæ in places curved, and some undulatory extinction. A little orthoclase may be present.

Quartz in irregular grains, sometimes rounded, especially when inclosed in hornblende; substance very pure, with almost no undulatory extinction.

Biotite, brown, with strong absorption, in irregularly shaped pieces, generally inclosed in the hornblende.

Magnetite, relatively abundant, in clusters and streaks of irregular grains.

An interesting outcrop of the hornblende schist occurs near Columbia University, and has been carefully studied by Professor J. F. Kemp and by myself. At the southwest corner of West One hundred and nineteenth street and Morningside avenue west a mass of micaceous gneiss, in large part pegmatitic, rises to a height of 20 feet, with steep slope to the south-

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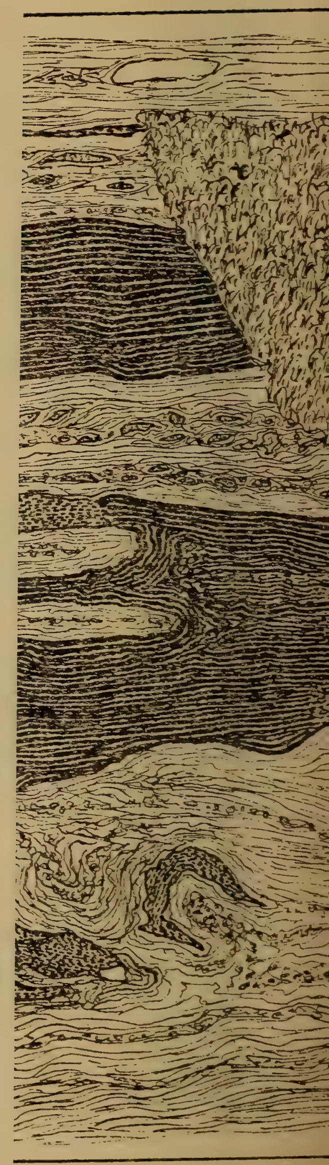
* Iddings, op. cit., p. 331.



nd West One Hundred and Nineteent
. At *A*, short apophysis shown in fig

east, partly covered by small patches of grass. The surface sketched (plate 61) comprises an area of 30 by 110 feet; strike north 31° east, 70°> west. Through this stratum, along the foliation planes, run nine parallel sheets (numbered at sides of plate) of quartz diorite or hornblende schist, passing in places into biotite schist or biotite gneiss.

These sheets vary in thickness from a few inches up to 7½ feet and are separated from 1 to 11 feet. Abundant seams of fine-grained pegmatite or aplite penetrate all the layers of both gneiss and schist, but only along the foliation planes. White quartz also occurs (*Q*) in scattered lenses, inclosed in or lying along layers of the schist, as well as in crumpled and crushed bunches at many points. The schist layers show more or less disturbance, flexure, and even zigzag folding, with variations in thickness and frequent passage at their margins into vaguely defined and crumpled layers of biotitic gneiss. Toward the southwest, crossing One hundred and eighteenth street, two of the sheets, numbers 4 and 5, are continued, the latter splitting again into two. Toward One hundred and seventeenth street three sheets occur, one sending out a small tongue or apophysis, and all die out toward the northwest corner of One hundred and seventeenth street. In the opposite direction, to the north, several seams of hornblendic and of biotitic gneiss are found, the latter displaying rather vague outlines and many flexures, mostly within Morningside park, opposite One hundred and twentieth, One hundred and twenty-first, and One hundred and twenty-second streets. These closely resemble those in the section into which the hornblende schist passes, and appear to mark the former range of the sheets of that rock in this direction. Thus the entire extent of the tract along the strike probably approximated 1,000 feet in this direction.

The schist consists mainly of an exceedingly compact, heavy, shining, jet-black rock with slaty lamination, with somewhat gnarled structure in some places, always with the hackly fracture usual in a metamorphic schist. In one of the thicker layers it is divided by a rhomboidal jointage into diamond-shaped blocks, a structure also observed in the same schist at west end of High bridge, One hundred and seventy-fifth street.

It also possesses generally a marked fibrous texture, with almost silky or even satiny luster, being a compacted aggregate of thin blades and elongated scales of black hornblende, 1 to 3 millimeters in length, lying parallel to the schist plane and mostly to each other, as well as apparently in close contact. Among them a few whitish particles appear, more distinctly on weathered surface (quartz and feldspar), and rarely yellowish particles of pyrite. Along some foliation planes thin seams of aplite penetrate, made up of granules of red orthoclase and gray quartz, and others glisten with films of black and brown biotite. A little

OUTCROP OF PEGMATITIC MICACEOUS GNEISS

The locality is Morningside avenue west, and West One Hundred and Nineteenth street. The gneiss is seamed by sheets of black hornblende schist partly covered by patches of grass. Passage into biotitic gneiss marked by broken lines. At *A*, short apophysis shown in figure 1, plate 63. White lenses of quartz (Q) and dotted of pegmatite. Thickness of sheet 3 at left margin is 5½ feet.

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epidote and apatite occur in some parts, but no calcite was detected by the eye.

Through variation in constitution from increase of biotite and addition of pegmatitic material, the schist changes in places into hornblendic gneiss, biotitic hornblende schist, biotite schist, and dark micaceous gneiss, richer in biotite than the contiguous country rock.

The following specific gravity determinations have been made on the schist from various localities, using lumps in distilled water at about 20 degrees Centigrade:

Locality.	Specific gravity.	
East Forty-third street, between Second and Third avenues	3.322	Epidotic.
East Sixty-ninth street to Seventieth street, near Second avenue	3.108	
West Seventy-ninth street, subway, in Central park	3.067	
West Ninety-second street and Riverside avenue	3.100	
One hundredth street and Fifth avenue	2.996	Epidotic.
West One hundred and nineteenth street and Morningside avenue west	3.270	
Same locality	3.119	Dioritic gneiss.
West One hundred and thirty-fifth street, near Eleventh avenue	3.138	
West One hundred and fortieth street and Seventh avenue	3.004	
West One hundred and forty-fourth street and Seventh avenue	3.113	
West One hundred and sixty-third street, on Croton aqueduct	3.029	Dioritic gneiss.
West One hundred and ninety-eighth street and Fort Washington avenue	3.003	Dioritic gneiss.
West Two hundred and seventh street and Prescott avenue	2.965	Dioritic gneiss.
Same locality (Spuyten Duyvil creek)	3.041	
New Rochelle, Westchester county	3.165	

MICROSCOPIC DESCRIPTION OF HORNBLENDE SCHIST

In addition to the thin-sections prepared from the schist at West One Hundred and Nineteenth street, mainly considered in the following description (slides A), others have been examined from nine other localities, namely:

B. Hornblende schist, West One hundred and twenty-second street and Saint Nicholas avenue.

C. Biotitic hornblende schist, East Fifty-second street and Madison avenue.

D. Hornblende schist (street unknown).

E. Hornblende schist (street unknown).

F. Quartz-diorite schist, on Speedway, One hundred and eightieth street and Harlem river.

G. Hornblende schist, Fordham, near Tremont street.

FIGURE 1.—HORNBLENDE SCHIST (× 90)

Hornblende plates enclose black hematite scales and white zoisite grains or perforations caused by their dislodgment. Groundmass, colorless mosaic of limpid plagioclase and quartz

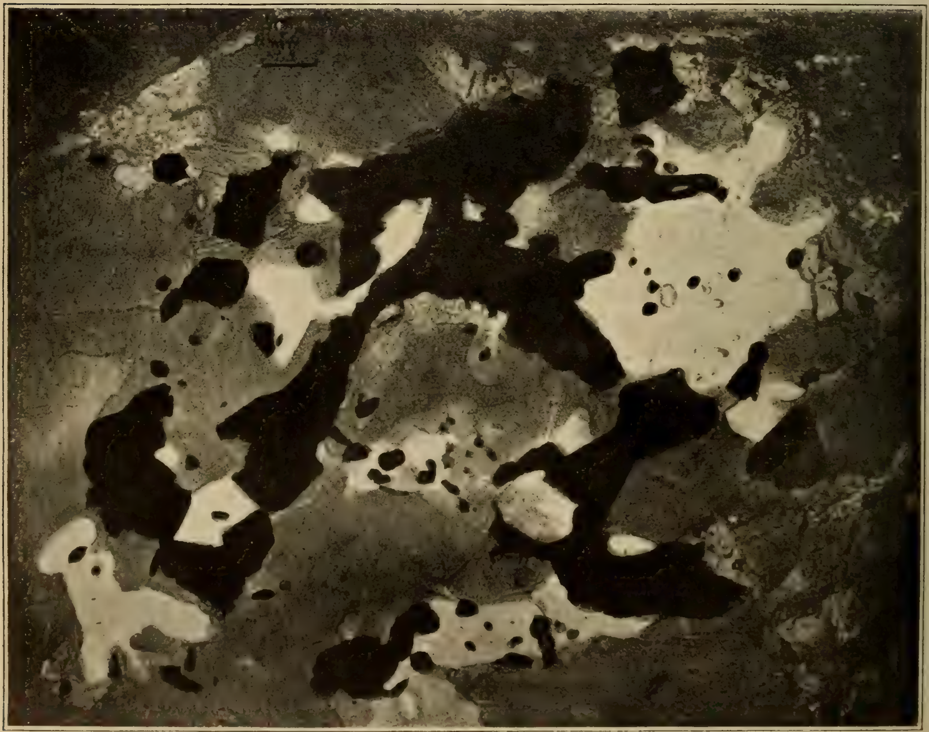

FIGURE 2.—HEMATITE IN HORNBLENDE SCHIST (× 72)

Rounded zoisite granules appear in quartz groundmass

PHOTOMICROGRAPHS OF HORNBLENDE SCHIST AND HEMATITE IN HORNBLENDE SCHIST

Morningside avenue west near West One hundred and eighteenth street

H. Calciferous epidotic hornblende schist, West One hundred and thirty-fifth street, near Eleventh avenue.

I. Quartz-diorite schist, West Two hundred and seventh street and Prescott avenue.

J. Epidotic diorite schist, One hundredth street and Fifth avenue.

In the thin-sections (plate 62) hornblende scales largely predominate, with more or less hematite and zoisite included or around their margins, and are separated by little patches of a limpidly clear and colorless mosaic of feldspars and quartz. As accessories, biotite, magnetite, zircon, and pyrite also occur. The paragenetic relationship appears to be as follows:

Zircon (rare), biotite, hematite, zoisite, hornblende, magnetite, feldspars, quartz, pyrite (and sometimes epidote and calcite). Nearly all of these grains or plates lie in parallel position, so marking the foliation plane, and with their longer axes parallel, so marking the fibration texture of the schist.

Hornblende occurs in short, brownish, and bluish green blades and largely in broad scales and shreds of very irregular forms, sometimes perforated with rounded holes (see figure 1, plate 62); average length, 0.4 to 1.2 millimeters. All lie in the schist plane and with longer axes approximately parallel; so that basal plates, in section normal to c, showing the characteristic cleavage at 124 degrees, are rarely met with except in thin-sections cut at right angles to the foliation (common in slides *B*, *F*, and *G*). Rounded inclusions of hematite and zoisite occur in these scales (see figures 1 and 2, plate 62), sometimes in juxtaposition; epidote also in other slides, generally in grains 0.04 to 0.06 millimeter long. The partial or complete dislodgement of these inclusions during shearing of the schist seems to have resulted in the rounded perforations, which present the same outlines, but are now occupied by the quartz-feldspar mosaic. Scheme of absorption, $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$; $\mathfrak{c}$, bluish green; $\mathfrak{b}$, brownish green; $\mathfrak{a}$, greenish yellow. Extinction occasionally parallel, on $\infty P \bar{\infty}$ (100), but 17 to 19 degrees, $\mathfrak{c} \wedge \dot{c}$. In slide *C*, hornblende in grains or short prismatic fragments. In slides *B*, *E*, and *I*, twins, with twinning plane parallel to clinopinacoid, $\infty P \grave{\infty}$ (010); absorption, $\mathfrak{b} > \mathfrak{c} > \mathfrak{a}$; $\mathfrak{b}$, deep brownish green; $\mathfrak{c}$, bluish green; $\mathfrak{a}$, straw-yellow. In slide *D*, zoisite inclusions as needles parallel to $\dot{c}$ axis of hornblende. In slide *F*, absorption $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$; $\mathfrak{c}$, dark bluish green; $\mathfrak{b}$, brownish green; $\mathfrak{a}$, straw-yellow. In slide *H*, hornblende reduced to bluish green scales, 0.2 to 0.5 millimeter in length. In slide *I*, extinction angle 15 to 16 degrees.

Hematite (specular iron), generally conspicuous in opaque, splendent scales, iron gray to brownish black, lying in schist plane as irregular groups, 1 millimeter or more in length, sometimes connected in rudely crescentic or hook-shaped masses (figure 2, plate 62). Where most abun-

dant, its disposal around the hornblende grains suggests an iron cement approaching the "sideronitic" texture of Duparc.* The smaller plates, up to 0.02 millimeter in diameter, are generally rounded or pear-shaped. The larger, about 0.1 millimeter in diameter, show rounded or imperfectly hexagonal outlines, sometimes marked with fine parallel lines, as from edges of overlapping lamellæ. Little rhombic forms also occur, as if produced by fracture and cleavage.

Magnetite in very small amount, as dull, iron-black fringes to hematite scales, rarely as minute isolated cubes, rectangular grains, or groups.

Pyrite, rarely, in minute granular coatings of brass-yellow color, around a hornblende fragment—usually a single instance in each thin-section.

Biotite, in a few brown plates, 0.2 to 0.6 millimeter long, sometimes two or three in the same thin-section; always imbedded in hornblende, lying in schist plane or obliquely. They inclose a few black angular particles (magnetite ?), and present the usual dichroism and strong absorption in plates normal to cleavage.

Zoisite, in colorless, elongated grains, almost idiomorphic, rarely reaching 0.6 millimeter in length, lying in close association with hematite, both as inclusions in hornblende scales or around their margins (plate 62). Though its prisms are mostly arranged with longer axes parallel to both foliation and fibration of the schist, those included in hornblende often lie in other positions, thus presenting cross-sections of rounded, many sided, six-sided, and rhombic forms. A majority are imperfect prisms, lath-shaped, roughly octagonal, and occasionally terminated, P (111) and $2\ P \breve{\infty}$ (021), with obelisk-like outline from the hemimorphic habit. Some traces of the brachypinacoid cleavage occur, $\infty\ P \breve{\infty}$ (010), usually in sections parallel to the prism faces; but cross-partings are common, much like those of the sillimanite in the adjacent micaceous schist, by which the mineral seems to have been largely broken up into angular fragments during rock movements. Though as an inclusion its boundaries are sharply defined, a transition appears in many places from colorless zoisite to green hornblende, around the margin of the latter, perhaps denoting a secondary growth of the former mineral; its relief is decidedly greater, and this excess in refractive index is well and simply shown by use of the Becke method. The central part of a prism is generally clouded by characteristic liquid cavities of irregularly rounded, elongated form, tubular, curved, and often branching, from 0.004 to 0.017 millimeter in length. Two methods of arrangement of these commonly prevail within a prism, fluid cavities along one side of the axis being disposed with their longer dimensions parallel, and on the other side normal to the vertical axis of the prism. This may also

* Rech. géol. et pét. sur l'Oural du Nord, Genève, 1902.

be the result of hemimorphic structure. Most appear completely filled with liquid, but some show a minute, fixed dark bubble. A few greenish scales of hornblende are also sometimes included in the mineral. From feeble double refraction the interference colors between crossed nicols rarely reach reddish orange of the first order in a thick section. Extinction parallel, but angles from 5 to 12 degrees or more are sometimes noted along division planes crossing this mineral and the contiguous hornblende; $\mathfrak{c} = \mathfrak{a}$. In convergent light, imperfect axial figures are observed; double refraction positive. In slide *C* a peculiar alteration of zoisite was noticed, into minute, colorless, micaceous scales. In *D* the proportion of zoisite arose to perhaps 20 per cent, but all in coccolitic form, as if crushed up into rounded and oval granules.

The groundmass filling the interstices of the hornblende blades presents a limpidly clear mosaic of closely fitted angular grains of feldspar and quartz, about 0.5 to 1.5 millimeters in length.

The feldspar consists chiefly of plagioclase, with a few inclusions of hornblende, zoisite, hematite, and rare, minute prisms of colorless zircon, with high relief. Near the margin of the thin-section occasional traces of cleavage occur. Between crossed nicols many grains present dual twinning; others are polysynthetic after the albite law, and a few also show the pericline twinning. Twinning lines are sometimes bent along a fracture through a grain, wavy extinction is common, and occasional instances of zonal banding are found. Determination of maximum extinction angles in sections normal to the albite twinning gave about 25 degrees, indicating labradorite (Ab_3An_4); the grains are entirely allotriomorphic.

The presence of orthoclase is suggested by a very few grains, without twinning, which possess zonal banding, wavy extinction, and approximately rectangular cleavage. In slides *C* and *G* feldspar is nearly or quite absent. It is also rare in *H*, where epidote occurs in abundance in pale yellow, pleochroic grains and rods, 0.1 to 0.4 millimeter in length. In *J*, epidote is still more abundant.

Quartz occurs in very variable proportion, almost absent in some slides (*G*), and up to 30 per cent of the volume in others (*C*). The quartz grains are surprisingly clear, with even fewer inclusions than those of feldspar. Fluid cavities are absent. Some grains are hypidiomorphic, showing two or three sides of a hexagon. Both quartz and feldspar offer all evidences, at least in their present form, of late development in occupation of the interspaces of the rock. Wavy extinction is general in both minerals, and often assumes a form which is not described, I believe, in the books. The darkening begins all around, at the contour of the grain, and, with continued rotation between the nicols, progresses

toward the center of the grain, with a rather distinct curved limit, to complete extinction. With continued rotation the shadow-line leaves the edge of the grain and advances toward the center, there shrinks and disappears. With rotation in the opposite direction, all these phenomena are reversed. The concentric strain-shadows, as they may be termed, plainly indicate the tension and optical disturbance produced by the pinching in of such grains on all sides through pressure surviving in the plicated laminæ.

One effect may also be here noted when, at a certain point during rotation, a closed curve is presented inside of the angular outline of the quartz or feldspar grain, which may simulate that of the original out-

FIGURE 2.—*Concentric Strain-shadows in Calcite Grain* (× 150) *observed between crossed nicols in thin-section of hornblende schist.*

Locality, Morningside avenue west, near West One hundred and eighteenth street.

line of a clastic grain in the process of secondary enlargement. The mobility and variation of this curved strain-shadow, however, in size and form, render its distinction easy.

Calcite occurs in occasional clear grains, showing the characteristic cleavage, and, between crossed nicols, concentric strain-shadows, sometimes with well defined central shadow of a deformed hexagon (figure 2). Minute nests, displaying the twinning stripes, are occasionally recognized in interstices of the other minerals, though never inclosed in hornblende. In slide H the crystal outlines of quartz are remarkably distinct in vicinity of the calcite seams, and concentric strain-shadows very common and strongly marked in grains of calcite, quartz, and feldspar.

CHEMICAL COMPOSITION OF THE HORNBLENDE SCHIST

Through Professor Kemp, I am enabled to present chemical analyses, made, at his request, by Doctor Jouët on a sample taken from many

pounds of pulverized schist, selected from a freshly blasted ledge at West One hundred and eighteenth street. I have been further indebted to Doctor Jouët for special efforts toward confirmation and completion of the results stated below.

	IV*a*.	IV*b*.	IV.
SiO_2	42.97	42.97	42.97
Al_2O_3	17.69	17.39	17.54
Fe_2O_3	5.09	5.36	5.22
FeO	13.04	....	13.04
MnO	.27	....	.27
CaO	10.00	10.04	10.02
MgO	6.41	6.37	6.39
K_2O	.33	.44	.39
Na_2O	1.66	1.58	1.62
H_2O	.34	.37	.36
CO_2	.72	....	.72
			98.54

No TiO_2 was found, nor, on examination of 5 grams of the rock, any evidence of Fl. The H_2O was inferred from loss by ignition. The composition of the schist presents an unusually high content of alumina, iron oxides, and earthy bases, whose bearing on the genesis of the rock will be discussed beyond. The cause of the loss, indicated in the summing-up, was not ascertained.

Dioritic Gneiss and Hornblende Gneiss

These rocks are always finely granular, with slaty lamination, made up, as shown on its delicately striped cross-section (plate 63), of alternate lamellæ, rarely over 0.5 millimeter in thickness, of black hornblende and of a gray-white mixture of quartz and feldspar. Biotite may abound on some glistening planes, and greenish yellow epidote, as thick seams, in masses of the gneiss which are crumpled and distorted. Specific gravity, 3.029, in a specimen from West One hundred and sixty-third street and Croton aqueduct. Nine thin-sections of these gneisses, from various localities on Manhattan island, were examined under the microscope.

Hornblende makes up from 30 to 50 per cent of the material, partly as well defined prisms, mostly as irregular scales and fibrous blades, all disposed in the schist plane, but without the mutual parallelism noted in the hornblende schist. On a cross-section, the usual cleavage traces at 124 degrees. Absorption scheme, $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$; $\mathfrak{c}$, bluish green ; $\mathfrak{b}$, brown-

ish green; $\mathfrak{a}$, brownish yellow. Maximum extinction angles, 17 degrees, $\mathfrak{c} \wedge \dot{c}$. Minute inclusions of epidote rodlets common.

In some slides plagioclase feldspar amounts to 10 or 20 per cent of the rock, displaying polysynthetic twinning after the albite, and in part the pericline law; the maximum extinction angles, on sections normal to the albite twinning, point to oligoclase. In others orthoclase may be the only feldspar, often the predominant one, up to 35 per cent of the rock, always allotriomorphic, showing distinct, almost rectangular cleavage traces, and generally clouded by decomposition, passing partly or wholly into a fine micaceous aggregate.

Quartz always reaches from 15 to 30 per cent, in clear, colorless grains, whose outlines show rounding in parts; the few inclusions comprise scales of light greenish amphibole (actinolite), needles of colorless apatite and minute zircons, but no fluid cavities.

A few grains of reddish garnet occur, sometimes reaching 5 per cent of the rock; the larger are full of rounded inclusions of quartz. Other accessories are scales of orange to brownish yellow biotite, attached to edges of hornblende; plates of iron-black menaccanite, sometimes in comblike or netted aggregates; minute crystals of pyrite, more or less decayed, and films of reddish iron oxide.

In the epidotic variety of the gneiss the amount of that mineral may rise to 15 or even 35 per cent of the volume, in prismatic fragments, sometimes including menaccanite plates; also in rods and rounded granules, oval and pear-shaped. Feeble pleochroism, yellowish to colorless. Extinction parallel to elongation, but occasionally reaching 33 degrees.

Zoisite may also occur, commonly inclosed within the hornblende, in colorless, rounded rods or prisms, with high relief.

The occurrence of hornblende in the gneisses of our series has been regarded usually as only a varietal form, a mere accident of molecular arrangement due to excess of certain bases in the prevailing biotitic gneiss. This view has been thus expressed:

> "Hornblende, anthophyllite and other masses . . . they are simply different conditions of the same elementary materials as the gneiss, merely different forms of metamorphism." *

But the common substitution of these hornblendic gneisses along the strike for outcrops of hornblende schist, or across the strike on opposite sides of a fold—the identity of their field phenomena with those of that schist, intricate foldings, epidotic alteration, etcetera—their frequent intercalation with or actual passage into that schist—all such facts imply that they represent transition forms of an original hornblendic matrix,

* R. P. Stevens: Ann. Lyc. Nat. Hist. N. Y., vol. viii, 1865, p. 116.

with proportion of feldspar varying from maximum in a gneiss to minimum in a schist. Their common invasion by pegmatitic seams and dikes has resulted in increment of orthoclase, and probably of menaccanite, titanite, and garnet. The rock thus varies from a quartz-diorite schist or dioritic gneiss to a true hornblende-orthoclase gneiss, with epidotic varieties.

Phases of Metamorphism

IN GENERAL

There are several interesting phenomena of structural change and of mineral development, generated during the metamorphism of the hornblende schist and gneiss, which should be next differentiated from these rocks in their original condition.

DEVELOPMENT OF ACTINOLITE

This mode of alteration of the hornblende is, particularly in microscopic form, almost universal, represented by pale, greenish blades and scales. That it is not of primary origin is shown by the appearance of alumina, separated from the black hornblende by this change, sometimes in the form of spinel, more commonly that of biotite or chlorite. With further progress of the alteration, the following varieties of actinolite and tremolite rocks have been thus produced.

Green actinolite schist, as, for example, at West Seventy-eighth street, near Amsterdam avenue, and at West One hundred and fifty-fifth street, 100 feet west of Tenth avenue, the present site of Trinity cemetery. This consists of a fibrous, laminated rock of yellowish green color, made up almost altogether of blades of actinolite, rarely exceeding 2 or 3 millimeters in length, parallel to the foliation, but imperfectly so to each other. The intervening white seams, often 1 to 10 millimeters thick, are occupied mainly by granules of quartz, but in part, at the West One hundred and fifty-fifth street locality, by flakes of a pinkish white mineral of aluminous odor on moistening and somewhat harder than kaolin. Some planes are rich in glistening scales of biotite.

Dana states:

> "A bed consisting chiefly of radiated actinolite occurs west of Kingsbridge, north of the Harlem river. . . . The looseness of texture shows that something has been removed, and this is probably, in part at least, calcareous material; and, if so, the bed should be classed with the limestone beds." *

Since this outcrop, however, lies on line of the strike of the dioritic gneiss on the south side of the stream, I think that this actinolite bed

* Am. Jour. Sci., vol. xx, 1880, p. 25.

represents only the alteration of that gneiss, with loosening produced by decay.

In a thin-section of the schist from West One hundred and fifty-fifth street, under the microscope, actinolite predominates in parallel laminæ, to about 55 per cent of the volume, as slender fibrous blades, 0.02 to 0.70 millimeter in length, rarely up to 0.04 millimeter in breadth, with cross-partings; somewhat dichroic, greenish to colorless, and with maximum extinction 17 degrees. The intervening laminæ, up to 0.12 millimeter in thickness, are occupied by clear granules of quartz to about 40 per cent of the rock. A few scales of biotite occur, copper-colored or orange-yellow; pleochroism, red to colorless. Zoisite is included in both actinolite and quartz, as colorless rounded granules, with high relief. A few small cubes of iron-gray magnetite and films of reddish iron oxide were also distinguished, but no trace of any feldspar.

Fissile actinolite slate, at One hundredth street and Fifth avenue. An exceedingly fine-grained and thinly lamellated schist of almost greenish black color, with specific gravity 2.996, which appears to be a strongly sheared form of the more common schist just described.

Under the microscope, the thin-section reveals an abundance of actinolite rods and scales and, in the groundmass, quartz predominating, with rare particles of plagioclase feldspar. The dark color of the rock seems to be due to the abundant shreds and scales of leather-brown biotite. A little zoisite is also present.

Tremolite schist, at West Fifty-ninth street, between Fifth and Sixth avenues. A finely fibrous, grayish white schist, resembling closely in texture and structure the black hornblende schist in the vicinity, but here made up entirely, to the eye, of parallel blades and fibers of tremolite, tightly compacted, with many surfaces and division planes stained by reddish and yellowish iron oxide.

Similar schists, often cream-colored, but with wavy schist planes, were found between West Fifty-eighth and Fifty-ninth streets, between Tenth and Eleventh avenues, and elsewhere in that vicinity (figure 9), which were made up chiefly of smooth, continuous whitish laminæ of aphanitic texture, commonly spotted with tremolite blades of very fine fibration and silky luster, lying confusedly in the foliation planes; specific gravity of the rock, 2.921.

Other varieties of tremolite rock or amphibolite are radial granular and with longer fibers, radiated asbestiform, often in part actinolitic, chloritic, talcose, and ophiolitic, first described under "hydrous anthophyllite" by Thomson, Gale,* and others.

* Mather: Op. cit., pp. 461, 582.

A thin-section of the tremolite schist first referred to showed the following composition under the microscope: Tremolite largely predominates in sheaves and fascicles of fine fibers, lying in all directions; partly, also, in well defined fibrous prisms, with cross-partings. Between the cross-nicols, the usual bright interference colors; extinction angles 3 to 6 degrees. The interstices between the fibers are occupied by films of iron oxide, yellow and red to gray. There is also a small amount of groundmass, in minute patches, colorless and feebly anisotrope, with grays of the lower first order as interference colors—probably talc.

Greenish gray mottled amphibolite, at West Fifty-eighth street, near Eleventh avenue. A very finely granular rock, almost aphanitic in texture, which is quite uniformly spotted with irregular blackish green grains, generally 1 to 3 centimeters long. There is commonly a coarse schistose structure (specific gravity, 2.844); but at many points the rock becomes almost massive, often shot through in all directions with fibrous prisms and blades of yellowish gray tremolite, glistening plates of talc, broad scales of blackish green chlorite, and rarely blades of actinolite. Under the pocket lens the predominant groundmass also reveals minute tremolite fibers and white scales of talc.

The additional varieties of this rock produced by hydration and serpentinization through a more recent process of decomposition are further considered under the head of serpentine.

DEVELOPMENT OF BIOTITE OR CHLORITE

The partial to complete alteration of hornblende, during shearing, into biotite was shown to some degree in every outcrop of the rock (plate 61). The initial stages of the process appeared in scattered scales of brown mica, inclosed in or adhering to the hornblende, often only distinguishable under the microscope. Exceedingy common are shining black films over the surfaces of division planes. Sheets of glistening black biotite schist or biotitic gneiss, often garnetiferous, mark the next stage, still retaining some scattered blades or scales of hornblende. Good examples were observed at West Ninety-second street and Riverside avenue; at East One hundredth street, between Third and Lexington avenues, and on the Speedway, near Dyckman street.

Then follows a purely biotitic gneiss or schist, or spangled or mottled micaceous gneiss, carrying both black and white micas. The latter differs from the prevailing gneiss of the Manhattan series, generally in a somewhat finer texture, greater richness in micas, and retention of many scales of both micas, which are long and bladed like those of the antecedent hornblende. Excellent examples were found at East Sixty-fourth

street on the East river; West Eighty-fifth street, just east of Tenth avenue; East Ninety-ninth and One hundredth streets, between Lexington and Fourth avenues; West One hundred and eighth street and Riverside avenue; West One hundred and twenty-seventh street, near Saint Nicholas avenue; West One hundred and sixty-fifth street, on path above the Speedway; West One hundred and ninetieth street and Amsterdam aveuue.

Through its great plasticity this biotitic or micaceous gneiss often bends about and incloses the bunches of less altered hornblende gneiss in a manner somewhat resembling a flow structure. Prominent localities were noted at West Ninetieth street, between Eleventh and Twelfth avenues; West Ninety-second street, near the Hudson river; West One hundred and forty-first street and Seventh avenue. At West Fifty-eighth street, between Ninth and Tenth avenues, a group occurred of four thin layers of slaty hornblende gneiss and one of black biotite gneiss, separated by layers of micaceous gneiss. At Fifty-seventh street, only 200 feet farther south along the strike, this entire group was represented by a single thick bed of black biotitic gneiss.

DEVELOPMENT OF EPIDOTE, CALCITE, AND SECONDARY HORNBLENDE

The former outcrop of hornblende gneiss at East Ninety-ninth street, between Fourth and Lexington avenues, was most instructive for study of the following phases:

(1) General distortion and crumpling of layers; their close intercalation with seams of granite or pegmatite and common intersection by seams or veins of white quartz carrying tourmaline and garnet.

(2) Passage into black biotitic gneiss, penetrated by hornblende blades, and in places into micaceous gneiss, with many long bladed scales of both black and white micas.

(3) Epidotic alteration of thin layers, with development of secondary hornblende in brilliant, jet-black plates and aggregates, some prisms reaching 2 to 5 centimeters in length. Scattered scales of biotite, sometimes chlorite, represented apparently the destination of alumina from feldspar and aluminous hornblende during production of epidote. Many minute, pale green blades were assigned to secondary actinolite. Seams of epidosite, bright greenish yellow and finely granular, have been thus formed, up to 8 centimeters in thickness. These are quartzose and have been evidently less plastic than those purely hornblendic. They showed their rigidity and brittleness by frequent fracture into isolated green bunches, still lying in line, often coated by black, secondary hornblende, penetrated by veinlets of albite and quartz, with lateral

linings of hornblende, and wrapped about with folia of micaceous gneiss. These results are illustrated by figure 3.

Calcite also is the constant companion of epidote; for example, at East Ninety-eighth street, between Third and Fourth avenues (associated with magnetite, scapolite, and perhaps wollastonite), West One hundred and tenth street and Ninth avenue, West One hundred and ninetieth street and Amsterdam avenue. The most interesting locality of such association is still within observation on the north side of West One hundred and thirty-fifth street, west of Amsterdam avenue. Here, in the huge crumpled mass of black hornblende schist, the bright greenish yellow seams, 2 to 5 centimeters in thickness, consist largely of epidote

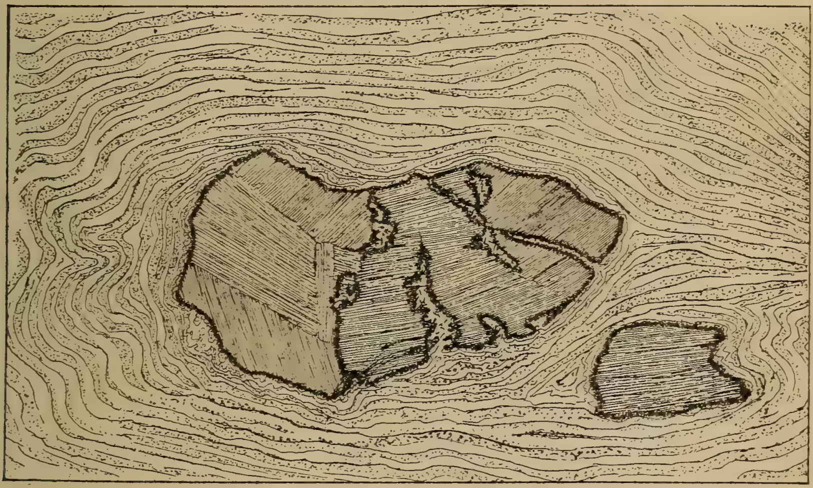

Figure 3.—*Yellow Nodules of epidotic Hornblende Gneiss imbedded in Micaceous Gneiss.*

The black coating is secondary hornblende. Veinlets of albite and quartz are shown. Locality, East Ninety-ninth street and Lexington avenue.

intimately mixed with quartz and partly or wholly replacing both feldspar and the original hornblende. Calcite alternates in parallel seams and thin lenses, sometimes 10 to 15 millimeters in thickness, often intermixed at the margins with epidote, quartz, and black prisms of recrystallized secondary hornblende. A large part of the schist is thus striped on cross section by yellow bands of epidosite, white seams of calcite, black layers of hornblende, and occasional granular bands of pegmatite; the yellow bands amount to 20 or 30 per cent of the rock. The calcite is evidently not original, but a secondary product, whose base has been dissociated from the calcareous minerals, plagioclase feldspar and hornblende, during epidotic alteration.

This general development of epidote in one of the heaviest beds of hornblende schist on the island, with an estimated thickness of at least 20 feet, indicates the favorable thermal conditions for generation of the mineral which prevailed during the intense compression and general disintegration of constituents, with partial pegmatization of the rock, which attended the intricate folding and crumpling.

Another good example of recrystallization of new hornblende may be seen in a short outcrop, about 60 feet long, of epidotic hornblende gneiss, at West One hundred and ninety-eighth street and Fort Washington avenue. This bed, which averages 2 feet in thickness, is bent sharply three or four times in zigzag folds, within a distance of 20 feet on the strike, north 48 degrees east, 85 degrees > southeast. The rock consists, to about 30 per cent, of brilliant plates or blades of jet black hornblende, commonly 3 to 5 millimeters in length, with a predominating ground-mass of gray quartz and white feldspar, with a little brown biotite, minute granules of garnet, greenish white actinolite, and greenish yellow epidote. Much pegmatite and gneiss material have been thrust between the distorted laminæ of the rock. A large part of the hornblende here appears to be secondary, and the extent of recrystallization suggests a strong tendency toward recovery, during metamorphism, of the granular structure of the original diorite, yet preserved at New Rochelle, Rye and Mamaroneck.

But at the nearest outcrop of the schist, to the north of this locality, the view that the development of epidote and calcite has not been connected with the process of pegmatization finds proof in their entire absence from the extensive and thick bed of dioritic gneiss at the locality on Spuyten Duyvil creek, notwithstanding the abundance of pegmatite throughout the mass in lamination seams and intersecting sheets. Slaty lamination is universal, but few folds occur and no corrugations whatever, indicating the absence of that intense local compression and permanent strain which apparently formed the essential condition for epidotic alteration.

With the discrimination of these later and secondary phases of alteration we are now prepared to consider the special subject of this paper—the genesis of these crystalline schists, with their burden of hornblende, intercalated as sheets in the Manhattan gneisses, from which that mineral is otherwise entirely absent. Three hypotheses call for consideration.

First Hypothesis: Metamorphism of Silicious Sediments

DERIVATION FROM ALUMINOUS CLAYS OR SHALES

Of the two classes of metamorphosed sediments which might possess a basic constitution similar to that revealed by the analysis of the horn-

blende schist (IV), one may have been derived from aluminous clays or shales rich in iron oxides, lime, and magnesia. Thus Dana accounts for part of the pyroxenite and hornblendite beds inclosed in the limestones of Westchester and New York counties:

"This association of the limestone with rocks containing much black mica or hornblende is, in fact, association with rocks containing much iron, as is indicated by the rusting tendency of the schists. This quality of these metamorphic schists is a consequence of the ferruginous character of the original sedimentary beds underlying or overlying the limestone strata. The iron of those sediments went, for the most part, at the time of metamorphism, to make the black iron-bearing mica or hornblende, the rest of it entering mainly into pyrite and sometimes garnet." *

A series of hornblende schists derived from such sediments has been analyzed by W. H. Melville: †

V. Pseudo-diorite, derived from arkose. Knoxville, California.
VI. Glaucophane schist, derived from shale. Sulphur Bank, California.
VII. Glaucophane schist, derived from shale. Monte Diablo, California.

	V.	VI.	VII.
SiO_2	50.44	49.68	47.84
TiO_2	....	1.31	....
Al_2O_3	8.18	13.60	16.88
Cr_2O_3	.48	....	....
Fe_2O_3	1.06	1.86	4.99
FeO	6.29	8.61	5.56
MnO	.21	.04	.56
CaO	11.55	10.96	11.15
MgO	17.63	6.26	7.89
K_2O	.50	.12	.46
Na_2O	2.98	3.09	3.20
H_2O	.98	3.84	1.98
P_2O_5	....	.21	.14
	100.30	99.58	100.65

But by comparison of these with analysis IV it appears that the hornblende schist of Manhattan, with its low percentage of silica and high content of iron oxides, mostly in ferrous condition, shows little relation to any of the above schists; nor, indeed, does that analysis approach those of unaltered clays or shales, since in the latter the content of silica usually much exceeds 55 per cent. In a highly basic shale from Clinton, Indiana, the amount of silica is but 43.13 per cent, but with alumina 40.87 and ferric oxide only 3.44.

* Am. Jour. Sci., vol. xx, 1880, p. 26.
† Bull. U. S. Geol. Survey, no. 148, 1897, p. 222.

On this hypothesis also the following published analyses* of foreign schists of the same mineralogical constitution as those of analyses V to VII have a bearing:

VIII. Hornblende schist. Milben, Germany.
IX. Hornblende schist. Treppenstein, Germany.
X. Amphibolite. Landeinwärts, Germany.
XI. Hornblendite. Rauhenthal, Germany.
XII. Palagonite tuff (average of 7 analyses), derived from basaltic ash. Iceland.

	VIII.	IX.	X.	XI.	XII.
SiO_2	48.9	46.7	46.0	46.4	47.9
TiO_2	....	2.8	....	6.7	....
Al_2O_3	26.3	4.3	4.1	4.6	13.5
Fe_2O_3	....	8.0	12.3	2.1	18.8
FeO	9.4	18.1	....	26.2	....
CaO	10.0	14.8	10.3	....	9.9
MgO	1.2	2.0	21.7	10.6	7.8
K_2O	1.0	....	....	....	.8
Na_2O	3.4	2.4	....	....	1.3
H_2O	....	.5	4.4	3.6	....
	100.2	99.6	98.8	100.2	100.0

These schists, VIII to XI, Rosenbusch separates from the igneous schists of his analyses (see XXIX to XXXI beyond), considering them of sedimentary origin. A comparison of their analyses with that of our hornblende schist shows wide divergence.

DERIVATION FROM BASIC VOLCANIC ASH

The other class may have been derived from layers of basaltic ash of extreme basic composition. To alteration of such material Jukes † attributed the hornblende schists observed by him in Ireland.

In Germany, at Berggieshübel, the beds of diabase tuff of the Lower Silurian have been altered, in contact with granitite, into actinolite—or anthophyllite—schist, often replaced with normal hornblende schist and augite-hornblende schist.‡ However, all recorded analyses of these basic tuffs (sideromelane, palagonite, etcetera,) § which are as rich in alumina and iron oxides as the hornblende schist of Manhattan, show a decided excess in silica, 4 to 7 per cent. The analysis of a tuff || which I have

* H. Rosenbusch: Tsch. min. u. pet. Mitth., vol. xii, 1891, p. 57.
† Student's Man. Geol., 1862, p. 169.
‡ Roth: Allg. u. Chem. Geol., vol. iii, p. 167.
§ Roth: idem, vol. ii, p. 301.
|| Roth: idem, vol. iii, p. 507.

found nearest in composition to our schist is given above in column XII. In view of the great amount and wide distribution of our hornblende schist, even beyond Manhattan island, throughout Westchester county, over a region of many square miles to the north and northeast, as well as along the Appalachian belt, it must obviously owe its origin to a material of common occurrence, likely to be included in recorded analyses of basic rocks.

Both forms of this hypothesis therefore seem to me untenable to account for the origin of our schist.

Second Hypothesis: Amphibolization of impure Dolomite

THE PROCESS OF AMPHIBOLIZATION

The efficiency of such a process, during metamorphism of limestone, has been long and generally recognized, so far as regards the earlier progress and products of amphibolization. The process has been thus described by Dana, with application to the amphibole and serpentine rocks at West Fifty-ninth street and elsewhere on the island, besides those in Westchester county, at New Rochelle, Rye, and elsewhere:

"When the magnesian limestones thus made were afterwards rendered metamorphic, part of the magnesia and lime . . . was in many cases made into silicates, such as tremolite, white pyroxene, and other species; or, when iron has also been present, into other related silicates of light or dark green tints, as hornblende, actinolite, green pyroxene . . . the darker kinds resulting when the all-pervading ingredient, iron, was present." *

Van Hise also explains:

"Hornblende schist may be produced from an impure dolomite or ankerite, the process being essentially the same as in the production of actinolite schist or actinolite-magnetite schist; only, on account of the greater multiplicity of bases present, hornblende is produced rather than actinolite." †

In application of this hypothesis to the present problem three facts call for attention:

LOCAL EVIDENCES OF PARTIAL AMPHIBOLIZATION OF LIMESTONE

The composition of the crystalline magnesian limestone in this region, within which it is generally admitted silicated solutions have brought about considerable metamorphism, has yet been shown by few published analyses:

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* Am. Jour. Sci., vol. xxii, 1881, pp. 115, 116.
† Op. cit., p. 703.

XIII. Dolomitic limestone. Inwood cross-valley, Manhattan island. J. F. Kemp.

XIV. Dolomite. Westchester county. J. W. Alsop, Jr.

XV. Dolomite marble, Tuckahoe, Westchester county. W. F. Hillebrand.

	XIII.	XIV.	XV.
CaO	38.42	30.75	30.68
MgO	10.29	20.30	20.71
Al_2O_3 and Fe_2O_3	1.16	....	....
FeO	....	.77	.21
CO_2	....	46.66	46.66
H_2O	....	....	.16
SiO_2 and insol	3.27	1.30	1.33
		99.78	99.75

Though the specimens analyzed contain very little alumina and iron oxide, dolomites have been shown to possess a large amount, reaching 7.68 per cent in one from Charlemont, Massachusetts, and even 9.60 per cent in a dolomitic marl from the vicinity of Stuttgart.* In the study of sedimentation, the passage of lenses of limestone into calcareous shales is familiar to every geologist, with still greater variation in the intermixture of carbonates with iron oxides and alumina. It would also appear that during the process of metamorphism of limestones no condition could be more unstable than the relationship of lime and magnesia carbonates to intermixed ferruginous, aluminous, and silicious impurities—no reaction, perhaps, in nature more ready, rapid, and thorough than the combination of these components into amphibole and pyroxene. Accordingly we find tremolite and diopside commonly distributed in little nests through the crystalline limestone at all its outcrops on Manhattan island, as well as at those north of the Harlem river, at Tremont, Tuckahoe, etcetera. Phlogopite is still more abundant near Inwood and Kingsbridge, evidently through the introduction of potassa, much of the rock passing into a phlogopitic calcareous shale. To the presence of alkalies the reaction may be attributed, resulting in feldspar and mica, at a point a little farther north, about which Mather says:

"Northeast from Sing Sing, the limestone becomes micaceous, and so modified as not to be easily recognized. Much of it is very fissile, and so much intermixed with mica and feldspar that it might with propriety be called a calcareous mica slate; but much of it contains so little carbonate of lime as to be distinguished with difficulty." †

* Roth, op. cit., vol. ii, p. 577.

† Mather, op. cit., p. 548.

At the same time the scarcity of iron is a significant feature in these intermixed silicates ; neither augite nor hornblende has ever been found in these limestones, and very rarely biotite, in small quantity. Beds of hornblende gneiss or schist occur in the gneisses not far from the limestones, but never in contact with them nor passing into them.

A curious association of granular limestones and dolomites with black hornblende schists has been elsewhere observed—for example, in the Grenville series of Canada and in parts of New York state, in Orange county and in Essex county—the Adirondack region, where large outcrops of limestone are " associated with black hornblendic schists, which often cover a much greater area than the limestone, and which are so characteristic that we have come to recognize them as an indication of the series."* But it does not necessarily follow that in any of these cases there must be a genetic relationship between the two rocks. The black hornblendic and pyroxenic schists and gneiss in that region have been attributed by the same observer to possible alteration of aluminous shales or of gabbroic intrusions.

COMPARISON WITH RESULTS IN MASSACHUSETTS

For satisfactory study of any tract of highly crystalline schists of suspected sedimentary origin we are fortunate in being able to refer to the investigation of similar schists in that broad metamorphic terrane of undoubted sediments, in less altered condition, which occupies the western part of Massachusetts. It comprises deposits of a great variety of constitution and in all stages of alteration, belonging to the Algonkian, Lower Cambrian, Lower Silurian, and Upper Devonian periods. My own work at Cummington, Goshen and Chesterfield in 1878 and during succeeding summers, has inclined me to put great confidence in the cautious conclusions deduced by Professor B. K. Emerson from his thorough research toward the solution of this difficult problem. It will suffice for my present purpose to refer briefly to some remarkable results.† The incipient products of alteration of impure argillaceous limestones and dolomites by the process above suggested have been found (including some better represented in eastern Massachusetts and elsewhere) to be the following:

Stage 1. Tremolite limestone or dolomite.
Actinolite limestone or dolomite.
Hornblende limestone or dolomite.
Diopside (canaanite) limestone (or augi-calcite).

* J. F. Kemp: Bull. N. Y. State Mus., vol. iii, 1895, pp. 329, 335, and Bull. Geol. Soc. Am., vol. 6, 1895, pp. 242, 246, 248, 251, 261.

† Geology of Old Hampshire County, Mass., U. S. Geol. Survey, Mon. xxix, 1898, pp. 147-155, 163, 282, 306.

Coccolite limestone.
Garnet pyroxene limestone.
Enstatite limestone.
Scapolite limestone.
Wollastonite limestone.
Olivine (boltonite) limestone.
Chondrodite limestone.
Biotite or phlogopite limestone.

Stage 2. Tremolite rock and schist.
Actinolite rock and schist.
Amphibolite, hornblendite and hornblende schist, and gedrite rock.
Sahlite, garnet, graphite, magnetite, epidote, or rutile amphibolite.
Diopside rock, pyroxenite, and pyroxene schist.
Enstatite rock and schist.
Wernerite (scapolite) rock.
Wollastonite rock.

Stage 3. (By decomposition:)
Calcite serpentine (ophi-calcite, serpentine marble or ophiolite, in part).
Dolomite serpentine (ophi-dolomite, ophiolite, in part).
Tremolite, actinolite, amphibole, or hornblende serpentine.
Diopside (or pyroxene or sahlite) serpentine.
Enstatite, bronzite, antigorite, or bastite serpentine.
Olivine (boltonite) serpentine.
Mica serpentine.
Tremolite, actinolite, or amphibole steatite.
Talc and chlorite schists.

As to stage 1, the incipient changes have been recognized throughout the dolomitic limestones of Manhattan island and Westchester county by permeation, in little nests, of tremolite, diopside, coccolite, phlogopite, and sometimes actinolite, scapolite, and biotite; but no traces of augite, hornblende, garnet, enstatite, wollastonite, olivine, or chondrodite have been anywhere observed in our limestones.

A few members of stage 2, according to Dana,* were represented by the amphibolite, actinolite, and tremolite schists at West Fifty-ninth street and Eleventh avenue and the pyroxene and hornblende rocks at New Rochelle; but in Massachusetts amphibolites derived from limestone are characterized by large intermixture with albite and oligoclase, with tendency to a peculiar pseudoporphyritic texture,† both features absent from the amphibolites of this region. Though alteration of limestone into diopside rock does not occur on Manhattan island, this is well shown in the lime quarries of a neighboring region, at Montville and Mendham, New Jersey; nor has pyroxenite, enstatite, scapolite, or wollastonite rock ever been found on the island.

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* Am. Jour. Sci., vol. xx, 1880, p. 32.
† Emerson: Op. cit., p. 304, etc.

As to stage 3, direct serpentinization of limestone, which is a marked feature of its alteration in Massachusetts, finds here but slight examples. The ophicalcite at West Fifty-eighth street will be considered beyond.

On the other hand, the amphibolites after limestone in Massachusetts show no tendency to form serpentine and steatite, as do those in the same region, associated with gabbro-like beds, olivine, and enstatite rocks of apparently eruptive origin. On Manhattan island a similar resistance to ophiolitic decomposition is shown by the dense black hornblende schist; traces of serpentine have been observed at East Ninety-fifth to One hundred and second street, and at West One hundred and twenty-second street, near Tenth avenue; but the serpentinization of amphibolite, actinolite, and tremolite schist, with development of much talc and chlorite, has been abundantly noted from West Fifty-eighth to Sixty-third street, near Tenth and Eleventh avenues (figure 9, page 488), as well as in the coarse hornblendites, diorites, etcetera, at New Rochelle, Rye, and vicinity.

A comparison of the characteristics and relationships of the limestones, amphibole rocks, and serpentines of Massachusetts, with those of Manhattan island, yields no reason therefore to favor the view of the derivation of our amphibole rocks from alteration of limestone.

DISCRIMINATION BY CHARACTER OF THE AMPHIBOLE

Some light might be thrown on the origin of amphibole rocks in Massachusetts through evidence as to the relationship between the green amphibolites and black hornblendites. Emerson observed the actual passage of black hornblende schists into limestone, and not only inclosure but intermixture therewith, so that in undecomposed rock a remnant of carbonates formed a common constituent. From the analyses by Eakins * of green and of black amphibolites the following averages of four analyses of each kind have been prepared:

	XVI.	XVII.
	Green.	*Black.*
SiO_2	50.02	49.82
TiO_2	.89	1.13
Al_2O_3	17.46	16.19
Fe_2O_3	2.11	2.66
FeO	7.93	8.82
MnO	.14	.12
CaO	8.21	9.21
MgO	7.74	8.07
K_2O	.52	.45
Na_2O	2.76	2.74
	97.78	99.21

* Emerson, op. cit., p. 303.

The little difference shown—a slight excess of iron oxides and earths in the black amphibolites—only impresses the identity of the two kinds. The approximation of these results to those obtained with hornblende schists of eruptive origin (analyses XXIII to XXXI) would seem to forbid discrimination on chemical grounds; so also Emerson concludes,* with reference to a black amphibolite from Washington, Massachusetts:

"I think it probable that the rock was derived from an impure limestone, but must leave its origin in doubt, because no lithological criteria can be found that will distinguish amphibolites derived from lavas or tuffs and those derived from impure limestones."

In the hope of acquiring a chemical criterion by determining the composition of the amphibole derived from limestone alteration, the analysis of black amphibolite of Goshen, Massachusetts, by L. G. Eakins, was selected for study. Professor Emerson kindly supplied me with a piece from the base of the "anvil," a form produced by weathering of the rock, which is described as "a quartz-hornblende rock, formed by the alteration of the limestone by reaction of solutions derived from the inclosing schists." † This displayed an obscure schistose structure, with irregularly waving white layers 1 to 3 millimeters thick and dark layers 6 to 9 millimeters thick; specific gravity, 2.832. The dark layers consisted chiefly of blackish green hornblende, rather soft, with fibrous, curved, shining surfaces, in irregular grains and flakes, up to 12 millimeters long, disposed somewhat parallel and in the schist plane. Under the pocket lens some whitish to gray quartz was found to be interspersed through the hornblende, as well as concentrated in the white layers. The microscopic constitution of the rock has been described in detail by Emerson.‡

As the slitted cross-section of the specimen possessed an area of only a little over 15 square centimeters, an enlarged photograph (× 3.28) was taken, and the photographic print, having an area of about 120 square centimeters, was itself subjected to the method of graphic analysis described beyond (see page 466) for determination of the proportion of its mineral constituents. The light and dark parts were separately cut out and weighed, with further correction for the smaller portions of each intermixed with the one and the other by application of Rosiwal's method to a thin-section of the rock. The following were the final results so obtained:

* Op. cit., p. 30.

† Emerson, op. cit., p. 195, and plate v, figure 1.

‡ Idem, p. 191.

Minerals.	Weight of paper-sections in grams.	Approximate specific gravity.	Product.	Percentage by weight.
Light colored...................	.9485	2.65	2.5135	29.09
Dark colored	1.2747	3.50	4.4614	70.91
	2.2232	2.83	6.2916	100.00

From the amount of P_2O_5, 0.23, in the chemical analysis, that of apatite was calculated, 0.55, and deducted from the percentage of the light-colored minerals, leaving 28.54 per cent for quartz. This mineral was found, in a thin cross-section of the rock, to consist of a mass of crushed granules. A little anorthite feldspar had been recognized by Emerson in porphyroidal spots, but was not present in my specimen. The amount of TiO_2, 0.50, was divided, to calculate the small proportions of rutile, 0.25, and of titanite, 0.62, detected by Emerson. From the amount of K_2O. 0.19, the percentage of biotite was calculated, 1.76, using the published analysis from Monroe, Connecticut. The aggregate of these three minerals was deducted from the above percentage of dark-colored minerals, 70.91, to obtain that for hornblende, 68.28. The disregard of the small amount of anorthite has tended to reduce somewhat the percentage of SiO_2 in the result (38.39) and so to increase the Al_2O_3, whose estimated amount, 23.41, doubtless exceeds the truth. The large estimated amount of H_2O, 4.48, probably signifies a state of hydration in the hornblende likely to be found in such a specimen of weathered amphibolite. This also tends to minimize the percentage of SiO_2. Only a small part of the H_2O (loss by ignition) is included in calculation of the molecular ratio.

The theoretical composition deduced (XIX, page 456) differs from that of a hornblende of igneous origin mainly in its smaller content of iron oxides. For comparison, the analysis (XX) is appended on a hornblende derived from granular limestone, associated with tremolite, titanite, chondrodite, and diopside.* It is apparent that hornblendes of this origin vary widely in composition, and that the question cannot be settled on chemical grounds.

Third Hypothesis: Metamorphism of basic igneous Intrusions

PREVIOUS INVESTIGATIONS

The inclusion of these dark schists, together with the serpentine, in the "Trappean division" of Mather, in his early report on this region, was a natural conclusion from the opinions prevailing at that time, par-

	Mineral constitution.	SiO_2.	TiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	MnO.	CaO.	MgO.	K_2O.	Na_2O.	H_2O.	P_2O_5.	Fl.
XVIII. Chemical composition		55.64	.50	16.27	1.22	7.20	.28	9.23	5.58	.19	.91	3.11	.23	
Calcite	Trace													
Carbon	Trace													
Rutile	.25		.25											
Titanite	.62	.19	.25					.18						
Ore	Trace													
Biotite	1.76	.70		.29	.13				.38	.19		.05		.02
Muscovite	Trace													
Apatite	.55							.30					.23	.02
Quartz	28.54	28.54												
Anorthite	(?)													
		29.43	.50	.29	.13			.48	.38	.19		.05	.23	.04
XIX. Hornblende	68.28	26.21		15.98	1.09	7.20	.28	8.75	5.20		.91	3.06		
	100.00	38.39		23.41	1.59	10.54	.41	12.82	7.62		1.33	4.48		
		639		229	9	147	6	229	191		21	249		
Molecular ratio		64		24					64					
		4		1.5					4					
XX. Hornblende, Edenville, N. Y.		42.97		11.90	3.08	13.84	.48	1.49	11.63	.88	2.73	.38		

ticularly in regard to serpentine. A similar view, already quoted, has been taken by F. J. H. Merrill, who has given much study to these rocks. L. M. Luquer and H. Ries, in 1896, were inclined to consider hornblendic schists at Bedford, in the northern part of Westchester county, as possibly metamorphosed diabase dikes.* The first careful discussion of this hypothesis in reference to Manhattan island was presented by J. F. Kemp in 1897, before the New York Academy of Sciences, and on December 28, 1898, before the Geological Society of America. To him I am indebted for the use of analyses and many suggestions. More recently D. H. Newland, in a paper on the serpentines of this region,† has also referred to the igneous character of the anhydrous ferro-magnesian silicates, regarded as the original rocks.

In reference to such a genetic relationship the following characteristics demand attention:

CHEMICAL COMPOSITION OF THE SCHIST

Its remarkable uniformity in physical features—texture, mineralogical constitution and structure—testifies to a probable uniformity in composition, a well known character of eruptive material in dikes ejected from a common magma; yet more definite appears the approach of Jouët's analysis (IV) to those of two igneous rocks of exceptionally basic constitution, stated below:

XXI. Gabbro. Northwest Minnesota. Stokes. ‡

XXII. Diabase greenstone. Lower Quinnesec falls, Wisconsin. R. B. Riggs. §

This consisted of brown hornblende, chlorite, epidote, and quartz, with menaccanite, leucoxene, traces of feldspar, and pyrite.

	XXI.	XXII.
SiO_2	45.66	43.80
Al_2O_3	16.44	16.08
Fe_2O_3	.66	9.47
FeO	13.90	10.50
CaO	7.23	7.81
MgO	11.57	6.54
K_2O	.41	.34
Na_2O	2.13	1.96
Ignition loss	.07	3.99
CO_2	....	.08
	98.07	100.57

* Am. Geologist, vol. xviii, 1896, pp. 241, 247.

† School of Mines Quart., N. Y., vol. xxii, 1901, p. 409.

‡ W. S. Bayley: Jour. Geol., vol. i, p. 712.

§ U. S. Geol. Survey, Bull. no. 62, 1890, p. 91.

We may next compare the analysis of our schist (IV) with those published of similar schists from American and foreign localities:

XXIII. Gabbro diorite, derived from hypersthene gabbro. Windsor road, Baltimore, Maryland. G. H. Williams.

This consisted of hornblende and anorthite, with pyrite, garnet, epidote, zoisite, apatite, magnetite, and, rarely, rutile and titanite.

XXIV. Hornblende schist, from gabbro. Lower Quinnesec basin, Wisconsin. R. B. Riggs.

XXV. Hornblende schist, from diabase. Lower Quinnesec falls, Wisconsin. R. B. Riggs.

This consisted of brown hornblende, chlorite, epidote, quartz, and feldspar, with menaccanite, leucoxene, rutile, pyrite, and calcite.

XXVI. Amphibole schist, from diabase porphyrite. Near Brown's valley, California. W. P. Hillebrand.

XXVII. Hornblende schist, from diabase. Grand Rapids, Wisconsin. M. Swenson.

It contained also FeS, 0.73; CaP_2O_5, 1.10, and traces of Cl and Fl. Percentage constitution: Hornblende, 65.2; orthoclase, 19.2; oligoclase, 9.1; apatite, 0.4; biotite, 2.0; magnetite, 0.4; pyrite, 0.7; limonite, hematite, and water, 1.3; quartz, 1.7, and generally some augite.

XXVIII. Hornblende schist, from diabase. Near Cleveland mine, Michigan. R. B. Riggs.

This consisted of hornblende and labradorite, with pyrite.

XXIX. Hornblende schist, from diabase. Marienhöhe, Germany. H. Rosenbusch.

XXX. Zoisite amphibolite, from diabase. Loisberg, Germany. H. Rosenbusch.

XXXI. Actinolite rock, from diabase. Schapbachthal, Germany. H. Rosenbusch.

Concerning the derivation of the last three rocks Rosenbusch states: "They bear fully the character of eruptive rocks. They agree very satisfactorily with the composition of many diabases and gabbros (in part, rich in olivine)." *

XXXII. Schalstein, from diabase. Reitsch, Germany. R. Weinholdt.†

This is added to represent an intermediate stage of alteration between a diabase and hornblende schist, and selected on account of its low percentage of silica, like that of our hornblende schist (IV).

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* Loc. cit., p. 58.

† Tsch.' min. u. pet. Mitth., 1871, p. 108.

	SiO_2.	TiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	MnO.	CaO.	MgO.	K_2O.	Na_2O.	H_2O.	CO_2.
XXIII..........	46.68	....	17.12	2.18	7.61	Trace	13.46	10.34	Trace	1.75	.88	....
XXIV..........	49.19	....	18.71	5.03	4.04	....	5.92	7.98	.77	1.44	5.05	....
XXV..........	44.49	....	16.37	5.07	5.50	....	7.94	7.50	.56	2.59	4.99	5.38
XXVI..........	54.13	.46	14.53	1.50	5.25	.26	4.91	10.93	.32	3.53	4.21	....
XXVII..........	52.39	....	16.13	1.64	1.44	.82	8.76	4.70	1.42	2.59	.17	....
XXVIII..........	46.31	....	11.14	....	21.69	....	9.68	Trace	....	6.91	4.44	....
XXIX..........	48.2	.04	17.9	5.3	5.0	....	10.9	8.1	2.7	.5	1.5	....
XXX..........	47.3	.4	16.9	1.7	5.6	....	13.3	11.3	.4	4.3	....	....
						P_2O_5.						
XXXI..........	50.0	....	13.4	4.3	7.3	.6	8.1	11.0	1.6	2.6	1.7	....
XXXII..........	43.77	Trace	17.07	4.17	7.14	....	9.32	6.22	.81	3.15	5.63	4.02

In comparing the analysis of the hornblende schist of Manhattan (IV) with the foregoing, the following differences are apparent:

First, its low content of silica, agreeing only with the figures in XXV and XXXII, and, secondly, its excess of iron oxides, only equaled in XXVIII.

A comparison of the analysis of diabase greenstone, XXII (which closely approached that of our schist, IV), with that of the derivative hornblende schist, XXV, shows in the latter a notable loss in iron oxides and (on deduction of carbonates) in earthy bases. From the investigation of Rosenbusch (place cited), it has been too hastily inferred that the alteration of a massive rock into a schist has been generally attended with little change in chemical composition; but conditions of alteration have varied widely in different regions, and the Wisconsin rock has been probably subjected to a process attended with partial leaching out of silica and bases. To the varying amount of such leaching which has generally prevailed the variation of the analyses in the foregoing table may be reasonably attributed and their excess in silica and iron oxides over those in our schist.

The detection of fluorine in many samples of hornblende suggested that its presence or quantity, as the result of the action of mineralizers, might serve as an indication of trappean origin. A review of over 200 analyses of the mineral, reported by Dana, Roth, Rammelsberg, etcetera, yielded the following deductions: In 133 samples of amphiboles containing little or no alumina, fluorine was found in 18, from a trace to 1.16 per cent, especially in actinolites and tremolites. In 70 analyses of aluminous amphiboles, fluorine has been reported in 16, from 0.21 to 2.86 per cent. No definite conclusion could be drawn from the informa-

tion at hand, and so far as concerns the hornblende schist of Manhattan island, no fluorine could be detected by Doctor Jouët in his sample.

IDENTIFICATION OF THE HORNBLENDE

Comparison of methods of graphic analysis.—The peculiarities of the chemical analysis of the hornblende schist (IV) suggested a further effort toward deduction of the chemical composition of the hornblende itself. On account of the numerous minerals of the rock with closely approximate specific gravities, a process founded on dissection of the thin-section, akin to the "mechanical process" of Delesse,* seemed best fitted for the object in view.

For the various processes founded on measurement, drawing, or photography of mineral plates in a thin-section, I would suggest the general name of *graphic*. Such a process, with the ensuing calculation, may be based upon estimation of various dimensions. If the average diameter of the grains of a mineral, as seen in a thin-section, be represented by d, or the actual average area of its plates by a, the following possible conditions may enter into such calculation:

First, d. On relation to this, the "geometric rock analysis" of A. Rosiwal † is founded—the application of an ocular micrometer to successive measurement of length of cross-sections of plates, along a series of lines over a section of the rock, of such thinness that all the grains are cut by the two parallel faces. With a rock of uniform grain, especially one whose grains approach cubical form, coincident results may be expected from such a process; but the relation of the edges of a series of cubes can not, of course, be the same as that of the areas of their faces or as that of their volumes. The concordance of results presented in Rosiwal's determinations seems to me, therefore, to have been largely due to their mutual comparison rather than to comparison with some established standard, such as corresponding results obtained on the same rocks by some other exact process—for example, by means of liquids of high density. So far as the relation in question may yet be found sufficiently close for practical purposes, the process as described may be well applied, particularly to massive rocks of uniform grain, both as to cubical form and approximately equal dimensions.

Second, d^3. The volume of the mineral grain is beyond question the factor called for in all cases toward exact calculation. Where the average forms are nearly cubical and great inequality exists in the third dimension, thickness of the plates, of various minerals, d may well be deter-

* Compt. rend., vol. xxv, 1847, p. 544; Ann. d. Mines (4), vol. xiii, 1848, p. 379; Procédé mécanique pour déterminer la composition des roches, Paris, 1862.

† Ueber geometrische Gesteinsanalysen, Verh. Wien. geol. Reichs., vol. xxxii, 1898, pp. 143-175.

mined by the geometric process, or a by photographing or by drawing; but in the calculation little accuracy can be expected from dependence on use of either d, d^2, or a in place of d^3.

Third, $.7854\sqrt{d^2}$ or a. The prevalence or predominance of grains imperfectly filled out, and thus lacking cubical dimensions, in certain rocks—for example, many subcrystallized igneous and metamorphic varieties, rocks with spherulitic texture and conglomerates—indicates conditions of approach to spherical form and the propriety of use in calculation of the last formula to determine the proportional relationship of the true spherical volumes of such plates in the thin-section. The factor d may be estimated by the geometrical process, or a by the photographic process or by the drawing process of Sollas, which are described beyond. With the massive rocks, to which the foregoing three methods are applicable, the thin-section may be sliced in any plane.

Fourth, d^2 $(= a)$. In many foliated rocks this equation holds true, those whose grains are mostly isodiametrical on the schist plane, with uniform and less thickness, particularly thinly laminated rocks, most of whose elements are thin plates. In such, d may be determined on that plane by the geometrical process and then used as d^2 in the calculation of proportional volumes, or a determined directly by the photographic process or drawing process.

Fifth, a'. We have yet to consider those foliated rocks or schists in whose predominating grains one dimension much exceeds the others—those made up of elongated scales, blades, prisms, needles, and fibers. From the ease of splitting off a chip in such laminated rocks, their thin-sections are usually prepared from a flake so obtained. In these, however, the maximum areas of the elongated plates are presented, which would possess an exaggerated value in calculation of proportional volumes of the minerals. This fact is partly recognized by Rosiwal, who recommends:

"Für Schiefergesteine von hoher Parallelstructur genügt ein Bündel weniger paralleler in einer zur Schieferung annähernd senkrecht stehenden Schliffebene gelegener Mengenlinien," * et cetera.

His modification, however, is unnecessary in the simpler variety of foliation provided under the fourth condition, and in the remaining cases insufficient, in that it disregards the additional orientation of such a section, "approximately perpendicular to the schistosity," needed in reference to the direction of fibration and other conditions, in schists made up of parallel elongated elements. In these, three cases are to be

* Loc. cit., p. 148.

considered, for each of which the factor a must be directly determined by the photographic or by the drawing process.

A. Schists of uniform texture, made up of elongated elements of the predominant mineral, with equally thin intervening laminæ of the other minerals. Here it is only necessary, in an ordinary thin-section on the schist plane, to estimate the ratio of the average area of the plates of the predominant mineral, carefully measured on the schist plane, to their area a' $(= d'^2)$, in approximately correct proportion for the volume of that mineral in the rock, calculated from the theoretical cube of equivalent volume. The average values of the three dimensions of the plates of that mineral, length (l), breadth (b), and thickness (t), are ascertained in the common thin-section through a large number of measurements. Then,

$$\sqrt[3]{l \times b \times t} = d',$$

that is, the cube root of the average volume of the plates is equal to the length of side of cube of equivalent volume. Its square, d'^2, or face of cube, is the average area required for plates of that mineral, as seen in thin-section, in correct proportion to its real volume in the rock. The proportion of $l \times b : d'^2 :: a : a'$ yields the desired ratio of the areas of faces of the actual and of the estimated plates.

For measurement of the actual area the modification of the Delesse process by Sollas * may be employed, namely, drawing outlines of mineral plates with help of camera lucida in not less than 24 fields of the microscope, transferring to tinfoil, cutting out different parts, weighing together those representing each mineral, and multiplying by respective specific gravities; or with greater accuracy and ease, in my opinion, by directly dissecting the paper drawing itself, or still better by the process explained in the example beyond, namely, making one or more photomicrographs from parts of the thin-section, preparing, marking, and cutting out prints from the same. The average area of the plates of the predominant mineral so obtained is then reduced by the foregoing proportion to that of the true proportionate or estimated area, and the entire mineral analysis corrected to correspond.

In two following cases an additional thin-section, in a plane inclined at a definite angle to the schist plane, will become necessary to reduce error derived from the lack of uniformity in texture of some schists, likely to exceed any error produced by the practical difficulty in orientation of the slicing plane required. We may have to deal with contingencies modified by position of the blades, whether with parallel or with divergent axes, and whether with their planes in the schist plane or irregularly disposed toward it.

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* Trans. Roy. Irish Acad., vol. xxix, pt. xiv, 1891, p. 427.

If a plane of cross-section perpendicular to the schist plane runs also normal to the fibration, the short plates so obtained are always of diminished value, in calculation of areal proportion of minerals—linear and smallest of all where the planes of the blades lie in the schist plane.

If the same section plane runs parallel to the fibration, through parallel blades whose planes are irregularly disposed, the proportionate areal value may be excessive, as found on the schist plane. With planes of the blades in the schist plane, their sections are linear and their areal value too small.

If the axes of blades are divergent and their planes in the schist plane, or, it may be, irregularly disposed toward it, an estimate of their predominant orientation needs to be made to determine whether the conditions approach more closely to those of *A*, *B*, or *C*.

Ordinarily a section of the rock may be sliced at such an angle to the schist plane and to the fibration that the plates or sections of the blades in the new thin-section may present an average area, a' ($= d'^2$), in approximately correct proportion to the volume of the mineral in the rock intermixture. The more oblique the section plane, the larger, of course, the area of plates so obtained.

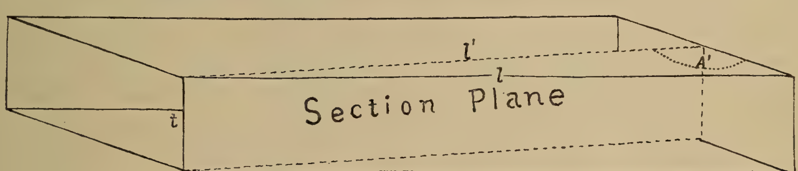

FIGURE 4.—*Diagram showing proper Section Plane inclineb to Fibration, in thick Blades.*

B. Schists of irregular texture, made up of prisms, thick blades, needles, or fibers of the predominant mineral, with approximately square cross-section, and with the other minerals in intervening laminæ of unequal or greater thickness. For a rock of this kind a thin-section might be sliced in some cases obliquely to the schist plane, as in *C;* but it may be generally preferable, from easier manipulation, to prepare a section normal to the schist plane, inclined obliquely to the direction of fibration, in the manner illustrated in figure 4. Then $\frac{d'^2}{t} = l'$; that is, if the average area, a' ($= d'^2$) of the plates of the predominant mineral required in proper cross-section, ascertained by the method explained before, be divided by the known thickness of the blades, we obtain the length of the plates (l') required in the proper cross-section. The actual average length of the plates on the schist plane being known (l), we have for the small triangle above on that plane the formula $\frac{l}{l'} = sin\ A'$; that is, the sine of the

complement of the angle required for inclination of the proper cross-section toward the fibration. From a thin-section so prepared the actual areas (a) of the different minerals are determined by means of photomicrographs or of drawings, and their proportionate volumes estimated as before. It is apparent, however, that such a normal cross-section in longitudinal direction of a blade can possess sufficient area only in prisms or blades of a certain thickness.

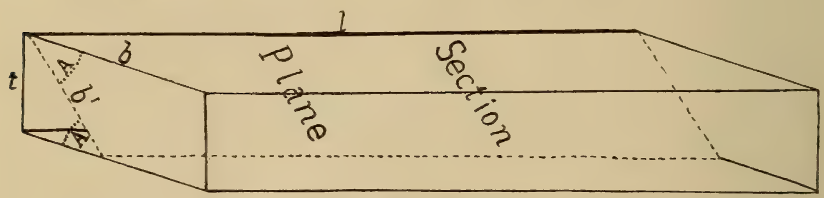

FIGURE 5.—*Diagram showing proper Section Plane inclined to schist Plane, in thin Blades.*

C. Schists of irregular texture, made up of thin blades of the predominant mineral, with the other minerals in intervening laminæ of unequal or greater thickness. In such a rock the section plane should lie with its axis in direction of the fibration, inclined at a certain angle to the schist plane, as illustrated in figure 5. In the small terminal right-angled triangle the desired angle A' ($= A$) may be calculated from the known factors, t (thickness of the blade), assumed to form the base of the triangle, and the breadth of the plate in the proper section plane, $b' \left(= \frac{d'^2}{l}\right)$, assumed to form the hypotenuse, by the formula $\sin A' = \frac{t}{b'}$.

From a thin-section sliced at that angle toward the schist plane, photomicrographs are taken, and by means of photographic prints or of drawings, as before, the actual areas (a) of all the mineral plates are directly determined and the proportionate mineral composition of the schist thereby calculated.

Sixth, a'. There still remains another class of rocks, chiefly coarse schists, whose folia may lie in all positions, without parallelism of either their planes or their axes toward each other or toward the foliation plane. According to their mode of distribution the texture of the rock may be uniform or irregular, with more or less imperfect schistose structure. Their treatment may be a matter of judgment as to closest approximation in texture to one of the preceding classes; otherwise the plan suggested for A of the fifth class becomes pertinent.

To recapitulate, the following is the procedure recommended :

SCHEME OF GRAPHIC ANALYSIS FOR DETERMINATION OF MINERAL CONSTITUTION OF ROCKS.

Methods.	Mineral grains (predominant)—form and size.	Rock examples.	Section plane.	Process.	Calculation.
		MASSIVE:			
I	Cubical; equal	Granular igneous—for example, granite, diorite, etcetera; quartzite, some sandstones.	Any	d by geometrical or a $(=d^2)$ by photographic or by drawing	d.
II	Cubical; unequal	Porphyries; breccia; some sandstones	Any	Same	d^3.
III	Rounded grains, thick lenses, or short spindles.	Spherulitic; imperfectly crystallized schists; conglomerates, and many detrital rocks.	Any	Same	$.7854 \sqrt{a}$ or d^2.
		FOLIATED:			
IV	Flakes and int. parallel and of equal thickness.	Sheared igneous; quartz, mica, and chlorite schists; some gneisses and sandstones.	Schist	Same	d^2 $(=a)$.
V		FOLIA ELONGATED			For V and VI first make measurements and estimate $d' = \sqrt[3]{l \times b \times t}$.
A	Prisms or blades and int. parallel and of equal thickness.	Some sheared igneous; many metamorphic schists—for example, amphibole, biotite, etcetera.	Schist	1. Make measurements and estimate d' 2. a, by photographic or drawing	$l \times b : d'^2 :: a : a'$.
B	Prisms (or thick flakes) parallel.* Int. of irregular thickness.	Porphyries, with parallel phenocrysts; sheared porphyries; compressed conglomerates; many coarse schists (for example, diorite, hornblende, staurolite, etcetera) and coarse sandstones.	Two needed: Section 1, schist Section 2, oblique to fibration (figure 4)	1. Measure and estimate d' on section 1 2. a' on section 2 by photographic or by drawing	a'.
C	Blades (or thin flakes) parallel.* Int. of irregular thickness.	Micaceous gneiss; thinly foliated schists (for example, amphibole, talc, chlorite, etcetera) and sandstones.	Two needed: Section 1, schist Section 2, oblique to schist (figure 5)	1. Measure and estimate d' on section 1 2. a' on section 2 by photographic or by drawing	a'.
VI	Any folia in every position	Coarsest schists—for example, ottrelite, many hematites, amphibolite, steatite, etcetera.	Schist or any	1. Measure and estimate d' 2. a, by photographic or by drawing	$l \times b : d' :: a : a'$.

* Also even if somewhat divergent on schist or in vertical plane.

ABBREVIATIONS.—d, measured average diameter of plates of predominant mineral; l, measured average length of plates; b, measured average breadth; t, measured average thickness; a, measured average area; d', estimated side of cube of equivalent volume; l', estimated length of proper section plane; b', estimated breadth of section plane; a', estimated face of cube of equivalent volume; $=$, area of proper section plane; *flakes*, isodiametrical folia of predominant mineral; *blades*, thin elongated folia, with rectangular cross-section; *prisms*, thick elongated folia, needles, or fibers, with square cross-section; *int.*, interlaminæ of groundmass.

Graphic analysis of the hornblende schist.—For the investigation of our hornblende schist, the fifth method appeared most suitable. By measurement of 50 crystals of hornblende, taken in succession as they occurred in passing over several fields under the microscope in the ordinary thin-section, made on schist plane, the following average dimensions were determined: Length (l), 0.95 millimeter; breadth (b), 0.32 millimeter; besides thickness (t), 0.09 millimeter, measured on a cross-section. Then the side of cube of equivalent volume,

$$d' = \sqrt[3]{l \times b \times t} = 0.3013 \text{ millimeter.}$$

The area of face of such cube, equivalent to area of plate required in proper cross-section,

$$d'^2 = 0.09078.$$

To determine the section plane by division C of the fifth method, the proper breadth of such plate,

$$b' = \frac{d'^2}{l} = \frac{0.09078}{0.95} = 0.095559,$$

that is, about one-tenth of the breadth of the thin blades actually shown on the schist plane.

$$Sin\ A = \frac{t}{b'} = \frac{0.09}{0.095559} = 0.9418$$

$$= nat.\ sin\ 70^\circ\ 20',$$

the proper angle at which a thin-section should be sliced, from the schist plane, to present the hornblende in exact areal proportion to its true volume in the schist.

In place, however, of slicing this additional thin-section, the division A of the fifth method was resorted to, as attended with least error in a rock of such homogeneity. In the usual thin-section on the schist plane, instead of drawing the outlines of minerals, after the Delesse and Sollas method, photomicrographs were made of each field studied, with low magnifying power (figure 1, plate 62), and two prints, 10 by 12.5 centimeters, obtained from each negative. On one, as a guide, the grains of each mineral were marked as identified under the microscope, and the other print carefully cut up under a reading lens, and the separate parts, representing each mineral, weighed together. Conditions of accuracy were found in the considerable weight of even such a paper sheet, between 2 and 3 grams, in the slight difference in weight between any two sheets, about 20 milligrams, and in the uniformity gained by use of a sufficient number.

No fixed method can be adhered to in application of the process; with each rock the procedure should be influenced, to some extent, by its chemical composition. In this case, to diminish error in connection with the heaviest grains, the ores, on account of their irregular distribution (plate 62), three separate determinations of these were made on such photographs, yielding the percentages (corrected by specific gravity for weight) 5.58, 4.60, 6.75. From these it was inferred that the percentage of Fe_2O_3, 5.29, in the chemical analysis, represented chiefly that of ores separated in form of ferric oxide. For the other constituents in the remaining 94.71 per cent the following determinations were made: The weight of paper pieces, representing hornblende, amounted to 1.9211 grams; the relation of areas in the actual and estimated plates (see A, method IV), was found to be $l \times b : d^2 :: 0.95 \times 0.32$ (= 0.304) : 0.09078. Then, 0.304 : 0.09078 : : 1.9211 : .5737; that is, the estimated area of plate in proper areal proportion to the true volume of the hornblende blades ought to be less than one-third of the actual area of the plates, as seen in thin-section on the schist plane.

Minerals.	Weight of paper sections (in grams).	Specific gravity.	Product of two preceding columns.	Percentage.	Percentage raised to true amount.
Quartz	.1110	2.65	.2942	9.01	9.08
Feldspar and calcite	.2432	2.70	.6566	20.12	20.28
Zoisite	.0631	3.20	.2019	6.19	6.24
Biotite	.0070	3.00	.0210	.64	.65
Hornblende	.5737	3.30	1.8932	58.01	58.46
	.9980	3.27	3.2635	93.97	94.71
Ores					5.29
					100.00

For discrimination of the ores, the application of a strong magnet to 2 grams of finely powdered rock of the original sample separated magnetite to the amount of 0.37 per cent. A few particles of pyrite also had been recognized in the rock and in its thin-sections. The remainder, the greater portion, consisted of hematite. The figures of the published analysis of biotite from Monroe, Connecticut, were used in calculation for the following statement; for the plagioclase feldspar, those of the analysis by von Rath of labradorite from diorite of Veltlin; and for

zoisite, the theoretical formula. The second line presents the chemical composition of the hornblende schist, as raised to 100 per cent from the analysis by Jouët.

	Mineral constitution.	SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	MnO.	CaO.	MgO.	K_2O.	Na_2O.	H_2O.	CO_2.
Chemical composition	....	43.62	17.80	5.29	13.23	.27	10.17	6.48	.40	1.64	.37	.73
Pyrite	Trace	....	....	....	....	....	....	....	....	....	....	....
Magnetite	.37	....	....	.25	.12	....	....	....	....	....	....	....
Hematite	4.92	....	....	4.92	....	....	....	....	....	....	....	....
Biotite	.65	.26	.10	.05	....	....	....	.13	.08	....	.03	....
Quartz	9 08	9.08	....	....	....	....	....	....	....	....	....	....
Calcite	1.66	....	....	....	....	....	.93	....	....	....	....	.73
Labradorite	18.62	10.48	5.13	.07	....	....	1.81	....	....	1.13	....	....
Zoisite	6.24	2.49	1.42	....	....	....	2.33	....	....	....	....	....
	....	22.31	6.65	5.29	.12	....	5.07	.13	.08	1.13	.03	.73
Hornblende	58.46	21.31	11.15	....	13.11	.27	5.10	6 35	.32	.51	.34	....
XXXIII	100.00	36.45	19 07	....	22.43	.46	8.73	10.86	.55	.87	.58	....
XXXIV	....	39.80	14.28	2.56	19.02	....	10.73	9.10	2.85	1.79	1.42	....

For comparison, I have appended (XXXIV) the actual analysis by Berwerth of black hornblende ("syntagmatite") from Vesuvius, to show the identity of our hornblende (XXXIII) in composition with that of volcanic origin.

DIKE-LIKE LINEAR EXTENSION OF OUTCROPS

From inspection of scattered exposures of the hornblende schist it might be inferred that if igneous they represent a series of intrusions of limited extent, squeezed up through fissures and mainly, perhaps, along foliation planes. Many examples of such mode of invasion by a series of short interrupted dikes along the division planes of a stratum have been elsewhere observed—for example, as illustrated by basalt dikes at Cripple creek, Colorado.* Few continuous outcrops of our schist have reached 100 yards in length along the strike. This common limitation, though characteristic of sedimentary lenses, may be otherwise interpreted. There are also some exceptions. Dana states that the thick hornblendic sheet at West One hundred and thirty-fifth street, near Tenth avenue, formerly reached from One hundred and thirty-third to One hundred and thirty-eighth street, over 1,000 feet. The outcrop on Spuyten Duyvil creek may yet be followed for a distance of more than 1,200 feet, and that at East Sixty-fourth street for 800 feet. The tract of amphibole rocks which stretched from West Fifty-fourth to Sixty-third street, near

* E. A. Stevens, Trans. Am. Inst. Min. Eng., 1903.

Eleventh avenue, reached over 2,000 feet. That near Morningside avenue, which I have been able to study in most detail, extended, with short interruptions, from West One hundred and eighth to One hundred and twenty-third street, fully 3,000 feet, including Morningside park and the adjoining heights, seamed with the dark sheets from end to end; hornblendic at the south, more biotitic toward the north, a good example of the latter being shown in the park, near One hundred and twenty-third street, at bottom of ascent of a path.

A section of the beds from west to east across the island, from river to river, at Ninety-seventh to Ninety-ninth street, was especially interesting for repeated outcrops of the hornblendic rock. Beginning near the Hudson river, in Riverside park, a contorted layer of black hornblende gneiss, 2 feet thick, in close association with pegmatite seams, lay in micaceous granitoid gneiss; strike north 41° to 51° east, 85° > southeast. Going eastward over a broad synclinal fold to the opposite side at Ninth avenue, this layer of hornblende gneiss, with about the same thickness, was found rising with dip 60° > northwest. Following over a narrow anticline of the prevailing micaceous gneiss to Eighth avenue, the hornblende gneiss again appeared in two or three parallel layers, each 1 to 6 inches in thickness and about a foot apart, in micaceous granitoid gneiss; dip 45° > southeast. Beyond this to the eastward the absence of exposure of the hornblende gneiss within Central park was due to the occupation of that part of the cross-section by the nearly horizontal layers of very micaceous gneiss, with mica schists, in the upper part of a broad synclinal fold. At Fifth avenue a layer of black hornblende gneiss, 2 to 3 feet in thickness, rose near the east side of the fold, very nearly vertical. Continuing eastward toward Madison avenue, beds of micaceous gneiss occurred on the east side of the syncline; strike north 33° east, 80° > northwest. Between Madison and Lexington avenues then followed a series of four sharp folds in hard, gray quartzose gneiss; strike north 39° east. Each of these four folds inclosed a group of three layers of fine-grained, compact, black hornblende gneiss, partly epidotic. The layers were each about 1 foot thick and 2 to 3 feet apart. In the anticline between Madison and Fourth avenues these layers stood nearly vertical. The three other folds between Fourth and Lexington avenues were reversed, with axial planes inclined to the eastward. Between Lexington and Third avenues another anticline carried the hornblende gneiss on each side in groups of three layers, each a few inches in thickness. Then followed low ground, without outcrops, to the bank of the East river at Hellgate, where the hornblende gneiss again appeared along the shore in small islets in the river and beyond on the shore of Long island at Hallett's cove. The many outcrops along this cross-sec-

tion of the Manhattan schists, nearly 2 miles in length, indicated the inclosure of a nearly continuous sheet of the hornblende gneiss from river to river, brought up to view on one side of every anticlinal fold and descending on the other. Combining this evidence with that from the cross-section at Fifty-eighth to Fifty-ninth street, there is reason to assume the existence of at least one interrupted sheet, here and there split up into thinner layers, closely adjacent, or perhaps two horizon planes in the Manhattan series, over which this basic material has been spread or throughout which it has been injected. In other words, a large number of these outcrops plotted on the map (plate 60) may after all represent but one or two intrusions.

INTERSECTION OF GNEISSES BY APOPHYSES

The characteristic form of these basic sheets, that of intercalated lenticular layers, is met everywhere in strong contrast by that of the later intrusions of pegmatite, which cut across all the beds in dikes and veins. Since the foliation of the gneisses is accepted as practically coincident in general with original bedding, it seems difficult to correlate their limited shearing with such complete distortion of an apparently large number of intersections by basic dikes—a distortion which at least has not extended to the later system of acid dikes.

In discussing this point with Professor R. W. Brock, of Kingston, Ontario, he has called my attention to the remarkable similarity of conditions in our Manhattan series to those of the same age in the West Kootenay district of British Columbia. There a heavy formation of schists occurs, the Shuswap series (assigned with probability to Cambrian time), which consists of mica schists, mica gneisses, crystalline limestones, dolomites, and quartzites. Intercalated among them dark hornblende schists were found, and white schists originally considered quartzites but later identified as aplites. For a long period no crossing of any beds of the series by either of these members was detected ; but it was found later that the whole series had been cut by a network of diorite, granite, pegmatite, and aplite dikes ; so that "a large proportion of the Shuswap and Cambrian schists represent igneous rocks which have been crushed and altered into their present conditions," and that "the oldest, as far as ascertained, consist of a series of basic dikes cutting the Shuswap group, but now in many instances so altered and foliated by pressure and other causes that they have the appearance of constituent beds."* Too much reliance can not therefore be safely given to nega-

*G. W. Dawson, Geol. Surv. Can., Ann. Rep., vol. vii, 1894, p. 32 A, and vol. x, 1897, summary, pp. 29-31 A ; see also side notes on Shuswap map sheet, Kamloops district.

FIGURE 1.—TWO LAYERS OF HORNBLENDE SCHIST ALTERNATING WITH WHITE PEGMATITIC AND DARK MICACEOUS GNEISSES

Small apophysis, 45 centimeters long, near center. Morningside avenue west near 119 street

FIGURE 2.—CONTACT OF HORNBLENDE SCHIST

Hornblende schist above passes into hornblende gneiss at junction; fine grained micaceous gneiss beneath; partly penetrated by pegmatite at lower margin. Morningside avenue above West 118 street

HORNBLENDE SCHIST LAYERS AND CONTACT

tive evidence on the intersection of gneisses by the hornblende schist, which prevails on Manhattan island.

There yet remains, however, some positive evidence on this point in the apparent survival of apophyses. At the West One hundred and nineteenth street locality a small arm (at A, plate 61), about 1½ feet in length, may be seen projecting from one of the layers of hornblende schist into the adjoining pegmatitic gneiss (figure 1, plate 63) in a fashion which suggests the survival of a sheared apophysis thrust out from a trap-sill. Another is seen close by, between One hundred and seventeenth and One hundred and eighteenth streets ; yet another, about 2 feet wide

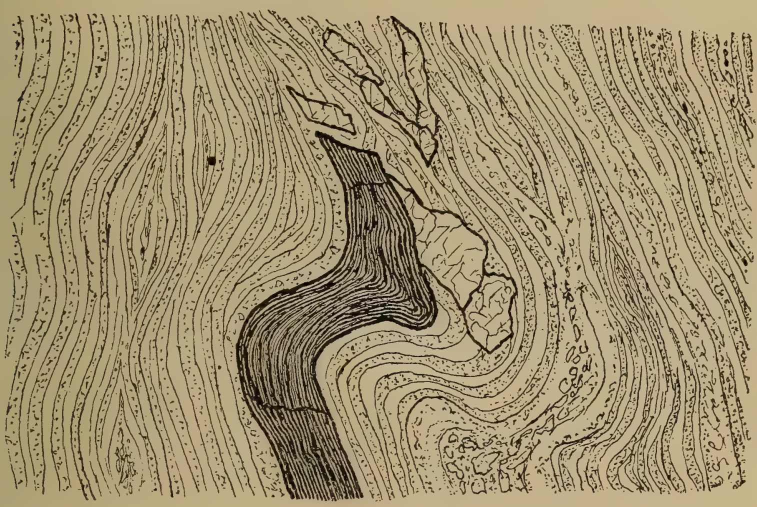

FIGURE 6.—*Tongue of Biotitic Quartz Diorite Schist* (*end of sheared layer?*) *in Micaceous Gneiss, with adjacent Lenses of Pegmatite.*

In Morningside park, opposite West One hundred and eleventh street.

in cross-section, is shown in similar position within Morningside park, opposite West One hundred and eleventh street, on east side of ascent of a path, close to the same avenue (figure 6). This, however, may be the sheared extremity of a sheet.

The street-cutting on west side of the avenue, 100 feet north of One hundred and tenth street, shows similar tongues of biotitic diorite gneiss, 1 foot thick below, thrust up between the layers of the micaceous gneiss and tapering off to a thin edge by the side of a sheet of the same diorite schist, 5 feet in width (figure 7). A similar one occurs at the outcrop on the Speedway, at about One hundred and ninety-third street.

In addition to these isolated projections of tongues of schist, there obtains a common gathering of thin layers in small groups, separated by a few feet or inches of gneiss, which looks like the result of shearing of a series of apophyses of a dike. Thus in the fine exposure of 3 layers of the hornblende schist on the bank of the East river from Sixty-fourth to Sixty-eighth street, one mass, 4 feet thick, in passing a few rods northward becomes split up into 8 or 9 thin sheets. This grouping of several separate layers needs, however, to be distinguished from instances of cross-section of several sharp folds in a single layer (West One hundred and tenth Street group), where a more uniform thickness tends to prevail,

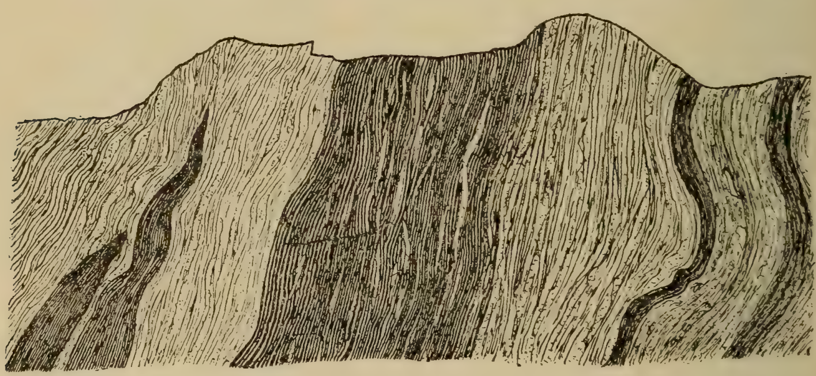

FIGURE 7.—*Emergence of Apophyses and Section of Sheets of biotitic Quartz-diorite Schist.*

Locality, Morningside avenue west, north of One hundred and tenth street.

and also from mere alteration of certain bands in a thick layer of hornblende schist into biotitic gneiss. The following are examples of such clusters of parallel layers in close approximation, those marked * being no longer accessible to examination:

4 layers at West Fifty-eighth street between Ninth and Tenth avenues (*);

4 to 11 layers at East Sixty-fourth street, on bank of East river;

3 layers, 1 to 5½ feet thick, in the subway through Central park at West Seventy-ninth street;

4 layers at East Eighty-ninth street and Third avenue (*);

3 layers at East Ninety-sixth street between Fourth and Madison avenues (*);

9 layers at West One hundred and tenth street and Morningside avenue west;

9 layers, at least, at West One hundred and seventeenth to One hundred and nineteenth street and the same avenue;

3 layers at West One hundred and sixty-third street, on the Croton aqueduct;

10 layers at West One hundred and sixty-fifth street, on path above the Speedway;

5 layers at west end of Highbridge, One hundred and seventy-fifth street;

5 layers at West One hundred and eighty-seventh street and Wadsworth avenue;
13 layers on the Speedway about West One hundred and ninety-third street;
5 layers on the Speedway near Dyckman street, etcetera.

The explanation of this local concentration of the hornblende schist in parallel sheets in close proximity may be connected with the method and the time at which their injection into the strata took place. If this had occurred after the compression of the gneisses into their general sharp folds by upward thrust along the more easily parted division planes, there would have been no tendency to close concentration of parallel sheets, and, amid the large number of outcrops of more gentle folds, little possibility of entire absence of intersection; of this the later system of

FIGURE 8. —*Diagrammatic Sketches illustrating two Periods in History of a Dike with its Apophyses, and first Effect of Shearing.*

Supposed to precede the results shown in plate 61.

acid or pegmatite dikes is a proof. Obviously, then, I think, their intrusion has preceded the folding of the strata, and this close grouping of sheets of hornblende schist may be the result of crowding down of clusters of apophyses whose line of union, the main dike or pipe, has thus become distorted, broken up, and effaced. Perhaps the finest example of this is shown at the outcrop on the Speedway (opposite Durands', about One hundred and ninety-third street), where a cross-section of 12 feet comprises 13 layers of hornblende schist, from 1½ to 20 inches thick. In such a mass of contorted layers, all parallel (as also in those at West One hundred and thirty-fifth street, near Eleventh avenue; West One hundred and sixty-fifth street, near Edgecomb avenue, etcetera), the plication may be safely attributed to lateral compression during folding of the stratum.

But in other cases the convolutions in a single layer of schist—for example, at West One hundred and twenty-fifth street near Claremont

avenue, and at West One hundred and seventy-fifth street, at end of Highbridge—admit of another possible explanation. It seems likely that on vertical pipes or vents of the dikes, often thin, and on upright parts of their apophyses the first effect of downward pressure has been wavy distortion and crumpling. Then followed their sidewise bending, parting, and rolling out on the foliation plane into zigzag corrugations, represented by part, at least, of the sheets showing this characteristic structure (number 4 in plate 61) in almost every outcrop. The mode in which such changes may have progressed in deformation of a dike and its apophyses is illustrated in two purely theoretical diagrammatic sketches (figure 8), with reference to the actual outcrop at West One hundred and nineteenth street (plate 61). The literature of dikes is extensive, but we have as yet scanty knowledge as to their earlier phases of distortion and metamorphism during conversion into schist, and to this these ancient dikes of Manhattan may offer a contribution. It will be further suggested in the summary of conclusions that these intrusive forms may have been of secondary character, of an entirely different origin and period, produced during progress of metamorphism of old igneous inclosures.

It may be added that the extent of such distortion of dikes included within these strata must also indicate a corresponding mashing and obliteration of the original bedding structure. Thus the adjoining micaceous and pegmatitic gneisses have assumed an imitative foliation with the same strike, though much contorted—for example, in Morningside park, along the Speedway, and elsewhere. In these it is now hopeless to search either for the original alteration of quartzose and of micaceous layers, suggestive of sedimentary origin, or for microscopic remnants of detrital structure. This is confirmed by the microscopic examination of the micaceous gneiss already presented (see page 427).

EVIDENCES OF CONTACT ALTERATION

In general.—The survival of results of contact action would be a desirable confirmation of the igneous origin of the hornblende schist, though their absence would not conflict with that hypothesis, in view of the common observation elsewhere of such absence of alteration by dikes crossing rocks of quartzose constitution, such as sandstones and gneisses, and even more sensitive materials—for example, shales and coal. There are three characteristic features to be looked for along the plane of junction between a dike and the country rock.

Sharp line of demarcation.—The blending of a sedimentary bed is rarely absent at one point or another along its margin with the contiguous

material. Thus, on Manhattan island, it has been remarked by Mather, Dana, Kemp, and Gratacap, that the crystalline limestone has been often found merging into the adjoining gneiss, of which a good example, called to my attention by Dr A. W. Grabau, may still be seen in the limestone outcrops at One hundred and sixty-fifth to One hundred and seventy-fifth street, along Sheridan avenue, north of Harlem river.

But the sheets of hornblende schist, on the contrary, are universally characterized throughout the island by their sharply defined lines of contact with the inclosing gneiss (see plate 63). Even in regard to the largest exposure of amphibole and serpentine rocks, that at West Fifty-ninth street (figure 9), this fact was long ago expressed with surprise by the earliest observer on record, Doctor Gale, who said:

"It is quite remarkable that, at the junction of the anthophyllite with the gneiss, it is so sudden that there is no intermixing of the two, but each remains perfectly distinct, side by side, a stratum of anthophyllite and a stratum of gneiss, and each pursuing its own peculiarity within the space of 3 or 4 inches of its neighbor." *

This feature, therefore, bears additional testimony to the common genesis of this amphibole rock with that of the adjoining hornblende schist, in opposition to the view of Dana as to the derivation of the former from alteration of limestone. †

Induration of a contact band.—Contrast is often shown by finer texture in the micaceous gneiss near its contact with hornblende schist (plate 63) than at a small distance; but the same differences obtain in ordinary beds of gneiss toward their division planes. This has been evidently due to more ready penetration of pegmatitic material along the central bands (figure 1, plate 63). As that might have been induced by looser texture and greater porosity at a certain distance from the hornblende schist, specific gravity determinations were made on lumps of the two rocks, in distilled water at 21 degrees centigrade, in a series across the contact (shown in figure 2, plate 63), to ascertain whether the density increased toward the contact line (see table on page 476).

There is here clearly no evidence of density increasing toward the contact line, as by the influence of a dike, but only oscillations caused by ordinary variations in density of layers, by permeation of pegmatitic material, and by degrees of decomposition of the weathered surface.

The survival of a contact band seemed more probable in the vicinity of a larger mass of the hornblende schist; but its absence from the 13-foot layer at West One hundred and sixty-fifth street above the Speedway, from the 20-foot layer at West One hundred and thirty-fifth street near Eleventh avenue, and from the 35-foot layer near Spuyten

* Mather, op. cit., p. 583.

† Am. Jour. Sci., vol. xx, 1880, p. 32.

Duyvil creek, indicates that whenever present it must have been very thin.

Distance in centimeters from contact line.	Kind of rock.	Specific gravity.
60	Pegmatitic hornblende gneiss........ .	2.993
30	Black hornblende schist..............	3.270
3	Hornblende gneiss....................	3.119
Contact line ——	Pegmatite seam, 1 centimeter thick ...	——
2	Laminated micaceous gneiss....... ..	2.811, 2.797, 2.776
5	" " "	2.837
6	" " "	2.779
10	" " "	2.762
14	" " "	2.776
15	" " "	2.846
19	" " "	2.789
22	" " "	2.770
25	" " "	2.808
37	" " "	2.777
52	" " "	2.796
67	Pegmatitic gneiss	2.806

Development of contact minerals.—Such alteration might consist of saturation of adjoining gneiss by the basic feldspar of the hornblende rock, or injection by augite or hornblende, or generation of new minerals along the contact line, such as tourmaline, biotite, or garnet, as would imply reaction through heat, fumarole vapors, or mineralizers. The amount of metamorphism of the Manhattan series could have hardly caused utter obliteration of any such naturally durable records in the marginal bands. From the absence of such observations by others as well as by myself, after a long search, it became apparent that certain necessary conditions—for example, presence of moisture—had been generally wanting; but a recent re-examination of sheets of hornblende schist, 2 to 18 inches in thickness, at the northeast corner of West One hundred and eighty-sixth street and Wadsworth avenue, revealed an abundance of biotite and also of garnets, up to 1 centimeter in diameter, both within the hornblende schist and in the contiguous pegmatitic gneiss, but only within a distance of 2 or 3 centimeters from the contact line. In thin-section the garnetiferous band of the hornblende schist shows an abundance of quartz and hornblende, with much biotite, granular garnet intimately mixed with quartz, and almost no feldspar.

It will be noted that garnet has never been found in the hornblende schist elsewhere on the island, though a notable constituent of the hornblende and biotitic gneiss. With this fact should be associated the abundant occurrence of garnet, in lumps 5 to 8 centimeters across, at outcrops

in Westchester county—for example, in black hornblendite, with grayish tremolite rock, coarse diorite, and serpentine, on Davenport's neck, near New Rochelle, there also doubtless a result of contact reaction.

PECULIARITIES OF CRYSTALLIZATION

Uniformity of texture.—Two forms may be sought for, characteristic of igneous intrusions, of which one is general uniformity in texture, corresponding to homogeneity in chemical and mineralogical constitution. This seems clearly to prevail through all the outcrops of our hornblende rocks. Besides the large series of rocks of the island in the collections of the department of geology at Columbia University, I have been enabled, through the courtesy of the curator, Dr L. P. Gratacap, of the American Museum of Natural History, to study the series at that museum, the more recent collections from excavations for 5 miles along the subway, and also the collection of the New York Mineralogical Club.

In texture the prevalent uniformity of the hornblende gneiss and schist is very striking, the blades and scales of the predominant mineral, hornblende, rarely exceeding 3 millimeters in length, though sometimes reaching 1 centimeter in certain thin layers—for example, at West Ninety-first street and Riverside avenue—or becoming coccolitic or granular—for example, at West Eighty-first street and Ninth avenue. It looks like a curious anomaly that its smallest dimensions, 0.5 to 0.2 millimeter, occur in nearly the thickest bed of the schist—that at West One hundred and thirty-fifth street. This has been caused plainly by the excessive folding, internal motion, mutual attrition of scales, and consequent comminution which have taken place within the thicker mass. In this fine grained schist the lessened tenacity shown by its peculiar brittleness and pulverulence is probably due to the minuteness of the binding scales.

In mineral constitution the uniformity has already been shown in the microscopical description of specimens from several localities (pages 435 to 438).

In chemical composition we have as yet only the evidence of the excellent analysis of Jouët, but I anticipate its confirmation by all future analysts.

Survival of phenocrysts.—Another peculiarity of an intrusive igneous material, often partly retained even in the product of its metamorphic alteration, consists in the separate crystallization of certain mineral constituents as phenocrysts. The detection of porphyroidal texture at several localities bears important testimony in favor of the igneous origin of this schist. The traces of this texture of occasional occurrence, however, need to be discriminated from an imitative metamorphic form. In

the latter, larger crystals of amphibole, long prisms, blades, and needles are not at all uncommon, recognized as due to secondary development of black hornblende, actinolite, and tremolite; these have been already described (page 444). Distinct from them there remain, in part of the hornblende schist and dioritic gneiss, obscure dark blotches or flattened flakes of rhombic, rectangular, or ovoid outline, 1 or 2 centimeters in length. Although under close inspection they turn out to be aggregates of ordinary grains of hornblende, they undoubtedly represent in some cases vaguely defined remnants of ancient phenocrysts.

In a search for survival of these forms the heavier beds of hornblende schist invited special attention. Small specimens from beds on the east side of the island have occasionally presented a very coarse texture, as if made up of columnar grains lying in all positions, but always consisting of hornblende. Similar coarse amphibolites were observed at the West Fifty-ninth Street locality, but always consisting of hydrated or serpentinized tremolite. The large bed at West One hundred and thirty-fifth street was found so thoroughly sheared, crumpled, thinly laminated, and epidotized as to forbid any hope of detection of original texture. Possible examples of porphyroidal texture, however, were noticed at the West One hundred and nineteenth street, One hundred and thirty-eighth street, and One hundred and sixty-fifth street localities.

In the largest bed of hornblende rock now left on the island, that on Spuyten Duyvil creek, the mass offers little evidence of pressure and distortion aside from some folding. Apparently in consequence of this, its material, a fine-grained dioritic gneiss, is quite uniformly mottled with dull black grains, 0.5 to 3.0 centimeters in diameter, at intervals of 1 or 2 centimeters. Their contours, though in part angular, are generally irregular, rounded, or ovate, resulting in a miniature augen-structure. Each grain is a composite aggregate of hornblende rods lying in various positions. These grains therefore represent altered phenocrysts of a ferromagnesian mineral in an ancient porphyry, with forms partially distorted by shearing.

STRUCTURAL EVIDENCES OF IGNEOUS ORIGIN

The harmonization of such opposite qualities, extremes of plasticity and rigidity in the same rock, shown by features of structure already described (page 429), yet calls for discussion.

In regard to the extraordinary plication of the hornblende schist, Dana offers the following explanation:*

"The presence of hornblende or hornblendic schist appears to have often determined a crowd of subordinate flexures and contortions in the beds, and a loss of

* Am. Jour. Sci., vol. xxi, 1881, p. 429.

distinctness in the minor layers. I have explained this on the ground that hornblende is relatively a fusible mineral (being of the grade 3, on von Kobell's scale of fusibility), while the feldspar (of which orthoclase is the prevailing one) and the mica (black and white) are of difficult fusibility (5 to 6, on the same scale), and, in consequence, beds that become hornblendic in the metamorphic process easily soften and bend. Such observations show why hornblendic metamorphic rocks, when containing little or no quartz, often fail of bedding, and look enough like igneous rocks to be frequently referred, without a question, to that class."

But thermal conditions concerned in metamorphism of schists, it is well established, have ruled far below the fusion point of hornblende (1060 degrees centigrade, according to Alb. Brun *), being generally estimated at a temperature of 150 to 650 degrees centigrade in presence of moisture. The plasticity therefore indicated by these corrugations must be due to some other cause. Subordinate conditions, apparently, have been the condensation suffered by the original coarse trap during its shearing into thinly laminated schist, as well as the softening and mobility promoted by the action of heated waters and mineralizers, shown by close and constant association with masses of pegmatite.

Yet more efficient has been the peculiar texture of the hornblende rock, made up of polished blades and plates, intermixed with slippery scales of hematite and biotite, the latter often developed and concentrated in continuous micaceous films. Under the intense pressures involved in mashing and folding of the Manhattan stratum, great differences prevailed in rigidity of different parts, varying from sandstone-like beds of compact quartzose gneiss, coarsely foliated micaceous gneiss, more fissile mica schist, and occasional thin sheets of trap. Both in these sheets and in the pliant micaceous layers adjoining we find all the properties to favor easy flowage during orogenic movements, with ready tendency to extreme variations in thickness, flexure, and distortion. As the general process has been explained :

"In a series or group of beds of different lithological character, the thick strong beds are less closely folded than the thin weak beds. The softer layers are greatly thickened here and greatly thinned there, as demanded by the stronger layers. The folding of the first may be comparatively simple and the second may be closely plicated." †

To this general action might have been added in certain cases, as suggested in a previous connection, the downward crumpling of the upright portions of the ancient dikes.

Again, in regard to the evidences of rigidity, brittleness, and fragility of the schist, shown by its fracture, faulting, and occasional brecciation,

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* Arch. de Sci. phys. et nat., xiii, p. 352.

† Van Hise, U. S. Geol. Survey, Ann. Rep., vol. xvi, pt. 1, 1894–'95, p. 596.

these results seem to be plainly connected with later impregnation and cementation of the trappean sheets by free silica. This has been illustrated by the quartz and pegmatite lenses shown in plates 61 and 63. The later intersection of the strata by pegmatite dikes has often followed the same planes of weakness, splitting up these basic dikes with new seams of pegmatite and quartz (as well shown in the upright section of hornblende schist, 40 feet high, at West One hundred and thirty-fifth street and Saint Nicholas avenue) and forming a second period of silicious impregnation. The convolutions and corrugations of the folded layers are themselves shattered and separated in such a way as to testify that their plasticity was an antecedent and temporary condition. The apparent incongruity of the two classes of phenomena was therefore founded on successive conditions of constitution, the physical qualities of the original, highly basic, crystalline trap, a gabbro or diorite, and the later characteristics of the more acid quartz diorite.

Schists at Other Localities

WESTCHESTER COUNTY

Hornblende rocks.—We gain further light by reference to similar schists in the region northeast of Manhattan island, and to those in other tracts of crystalline rocks.

A comparison with the hornblendic schists of Westchester county yields very satisfactory and decisive results. It had been already pointed out by early observers that intrusives are of common occurrence in that county.* We owe to Heinrich Ries the recognition and description of the tract of granite diorite, about 1 by 7 miles in extent, near Harrison, and also smaller tracts east of Portchester and Rye and south of Mamaroneck. This rock was found to consist of quartz (40 to 50 per cent), in part in augen form ; plagioclase, sometimes predominating over the quartz ; considerable orthoclase and biotite and less hornblende, and a small admixture of garnet, titanite, rutile, muscovite, microcline, zircon, apatite, and pyrite. The main mass was decidedly gneissoid, passed into mica schist, carrying sillimanite along the border, and was there generally seamed with numerous veins of coarse granite and pegmatite.† Mr F. J. H. Merrill has also stated : "Near the shores of Long Island sound the Manhattan schist is everywhere injected with bands, lenses, and dikes of pegmatite, granite, amphibolite, and pyroxenite." ‡

Many years ago I had studied some of the prominent intrusions near

* Mather, op. cit., p. 23.

† Trans. N. Y. Academy of Sciences, vol. xix, 1895, pp. 80 86.

‡ N. Y. State Mus. Rep., vol. L, 1896, p. 23.

New Rochelle, Rye, etcetera, and collected specimens now in the geological cabinets at Columbia University. The following is a brief description of the most important types from New Rochelle, with references to similar kinds at other localities in that region. Putting aside from present consideration the pyroxenic rocks or diabases which have been reported, all these hornblendic forms fall naturally into three classes:

A. Coarse to fine hornblendites and quartz diorites, the mother rock, varying merely in grain and in proportion of the feldspar-quartz groundmass.

B. Actinolitic diorites, hornblende gneisses, and hornblende schists.

C. Chloritic and ophiolitic amphibolites and schists, passing into serpentine.

Original hornblendites and quartz diorite.—At Davenport's neck, New Rochelle, occurs a coarse hornblendite. It is a heavy black rock (specific gravity, 3.128) made up of shining black grains and prisms of hornblende, 0.5 to 6.0 centimeters in length, often over 1 centimeter in breadth, entirely allotriomorphic and lying in all positions. A strongly marked prismatic cleavage produces the high luster of the fractured surface. These grains appear pure and free from inclusions, but in the interstices lie whitish nests of a mixture of grayish quartz, white feldspar, reddish garnets (rarely 4 to 5 millimeters across), reddish brown iron oxide, and a very few scales of black and white micas. In some specimens many cleavage planes of the hornblende are coated by red films of ferruginous marmolite, showing the first stage of alteration of the rock to serpentine.

Under the microscope a thin-section appears to be made up chiefly of elongated grains of hornblende, with rude boundaries, eminent prismatic cleavage, few inclusions of magnetite and sometimes epidote. Absorption scheme, $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$; $\mathfrak{c}$, bluish green; $\mathfrak{b}$, pale brownish green; $\mathfrak{a}$, greenish yellow. The small interspaces between the sides and ends of these grains are occupied mostly by granules of a plagioclase, with twinning after the albite and rarely the pericline law. These inclose minute translucent scales of pale green secondary amphibole (actinolite) and grains of epidote, magnetite, and hematite. Many show wavy extinction; on the albite twinning lines, by Lévy's method, the maximum extinction lines approach 44 degrees, indicating anorthite. A very little quartz may be distinguished among the feldspar grains, and in extinction often shows the concentric strain shadows elsewhere described. Biotite is moulded around the ends of the hornblende grains in small, irregular brown scales. Epidote is commonly dispersed through the interspaces in orange to brownish red, cloudy crystals, nearly colorless when minute, with high relief, often gathered into groups. Pleochroism, yellowish, reddish, and colorless; the usual high interference colors. The crystals are mostly elongated and six-sided, approximately in plane

of symmetry, but so small as rarely to show cleavage traces and cracks. A few dull black granules of square or rectangular outlines are probably magnetite, and hematite also occurs in thin but opaque plates of high luster and sometimes rhombic form.

One mile north of Rye is a similar rock (black hornblendite) in which incipient actinolitic alteration has produced a slight greenish tinge. Red iron garnet is distributed in particles throughout and sometimes gathered in coarse masses, up to 6 centimeters in length, mixed with black hornblende and greenish white plagioclase.

Under the microscope hornblende predominates, with the optical characters as described, with maximum extinction angle 18½ degrees $\mathfrak{c} \wedge \dot{c}$; a little feldspar in the interspaces; some colorless zoisite and reddish epidote, in hexagonal crystals or rodlets, as inclusions in hornblende, and a few minute shining plates of hematite, black and opaque.

At New Rochelle occurs a finer grained variety of the hornblendite, an epidotic diorite schist, showing bright facets of black hornblende, 2 to 4 millimeters long, with a little grayish feldspar interspersed. A little quartz and greenish yellow epidote are scattered throughout. Some specimens are streaked on cross-section by parallel seams of yellowish feldspar and epidote, 1 millimeter thick.

Another variety with less feldspar is a coarse black diorite at Larchmont manor.

Under the microscope a thin-section of the quartz-diorite schist of New Rochelle is found to consist to about 50 per cent of hornblende, mostly in irregular scales, largely fragmental, with rounded scolloped indentations; a few basal sections, with the cleavage at 124 degrees. Absorption scheme $\mathfrak{b} > \mathfrak{c} > \mathfrak{a}$; $\mathfrak{b}$, brownish green; $\mathfrak{c}$, bluish green; $\mathfrak{a}$, pale brownish yellow. Extinction somewhat variable, but 17 degrees in those with traces of eminent cleavage. Plagioclase abundant to about 30 per cent; clear, colorless, and with the albite twinning. Maximum extinction angles on sections normal to twinning plane seem to indicate a more acid feldspar than usual in these rocks. Occasional grains of orthoclase, marked by absence of polysynthetic striation, cleavage traces approximately at right angles and slightly lower interference colors than those of the plagioclase. About 5 per cent of quartz occurs in limpid grains, with few inclusions. Hematite common to about 12 per cent in rounded black plates of high luster, some displaying six-sided or rhombic outlines. These are inclosed in part in the hornblende, and in part among or around the plagioclase grains. A little secondary hornblende or actinolite is found in the quartz as pale greenish to colorless blades. Zoisite in colorless grains, with cleavage traces or rude cracks, rough surfaces, and high relief; elongation parallel to $\mathfrak{c}$; parallel extinction; interfer-

ence colors sky blue of second order in the rather thick section; vague axial figures. A little epidote, in pale yellowish granules, with feeble pleochroism; inclosed in the feldspar, sometimes in the quartz.

In the hand specimen this rock differs decidedly in texture and in proportion of feldspar from the hornblende gneiss of Manhattan island; but the closer inspection detailed in the above description shows a remarkable resemblance, almost identity, in mineral components and in their optical characteristics.

There is a hornblende gneiss at Larchmont Manor identical with the hornblende gneiss in parts of the hornblendic outcrop at our locality in West One hundred and nineteenth street. The scales and blades of black hornblende are mostly less than 1 millimeter long.

This gneiss is commonly distributed near New Rochelle and throughout Westchester county, often passing into black hornblende schist identical in appearance with that of Manhattan island.

Metamorphic diorites.—The fine-grained quartz diorite (New Rochelle) is a dark green compact and finer grained variety, with granules of amphibole, in part greenish like actinolite, rarely reaching 1 or 2 millimeters across. The amount of feldspar and quartz in the interstices is nearly equal to that of the hornblende. With increase of actinolite we find the next varieties.

The blackish green amphibolite (New Rochelle) is a dense, heavy rock, made up chiefly of a very fine groundmass, shot through in all directions by slender blades of black hornblende, 2 to 6 centimeters in length and about 2 millimeters in breadth. The groundmass exhibits under the pocket lens minute scales of dark green amphibole or actinolite and black mica with grayish particles (probably quartz and feldspar). A few nests here and there of finely saccharoidal white quartz, up to 3 centimeters in length, show rare facets of white feldspar, and are penetrated in every direction by well crystallized blades of hornblende showing the prism faces and pinacoids sharply defined.

The banded epidotic diorite (New Rochelle) is a blackish green rock, rich in slender actinolite blades, with much quartz, a little feldspar, epidote, black mica, and rarely garnet. There is also a finer grained variety.

Nearly all the hornblende of the actinolite diorite (New Rochelle) has passed into the dark green actinolitic form, intermixed with epidote. White plagioclase is present in large amount, with some grayish quartz.

The dark green actinolitic schist (New Rochelle) resembles the first form, with the green amphibole predominating in slender needles up to 2 millimeters in length, producing a silky luster. In some specimens nests occur rich in white feldspar, up to 2.5 centimeters in length.

The correspondence of this schist to those already described on Manhattan island suggests a similar metamorphic history.

Chloritic and ophiolitic amphibolites.—The gray chloritic amphibolite (New Rochelle) is a coarse variety, with allotriomorphic prismatic grains of dull, greenish gray amphibole, 1 to 3 centimeters long, lying in all positions; by weathering these become fawn-colored and look like tremolite. Chlorite, in dark green scales, sometimes with talc, forms shining films on cleavage planes of the amphibole. Much grayish feldspar (and a little quartz?) occupies the interspaces.

A similar mottled and coarse amphibolite at Rye shows also abundant flakes and grains of white marmolite and yellow serpentine.

A somewhat finer grained variety is represented by chloritic tremolitic diorite or amphibolite. It is a rather coarse rock, consisting chiefly of black hornblende, passing into brownish gray tremolite, up to 1 centimeter in length, lying in all positions; much plagioclase, snow white to grayish yellow, in the interstices; shining scales of blackish green chlorite abundant, 5 millimeters or more across, often spotted with whitish films (marmolite?).

A finer grained amphibolite is common at Rye, dark green, with actinolite needles not exceeding 3 millimeters in length. Others are of a lighter grayish green, glistening with minute scales of talc and chlorite, intermixed with larger flakes of marmolite or sometimes abundant white calcite.

The ophiolitic amphibolite (New Rochelle) differs in the general alteration of the long hornblende prisms to a brownish gray amphibole or tremolite, accompanied by a large amount of intervening blackish green groundmass, consisting apparently of amphibole, chlorite, and serpentine. Some thin segregated seams of white marmolite occur here and there.

In the thin-sections, under the microscope, deep green spinel, black iron ores, and some brownish iron oxide are distinguished.

Of serpentine (New Rochelle), there are several varieties, for whose description it is sufficient for my present purpose to refer to the papers of Dana, Merrill, and others.

An examination of this interesting series from the region northeast of our island has thus shown all transitions from coarse intrusive rocks, evidently nearly related to the quartz diorite of the Harrison tract, but more basic, through metamorphic forms in which the hornblende shows all stages of alteration toward actinolite, and, by shearing, into dioritic and hornblende gneisses and schists which closely approximate, though perhaps they do not quite reach, the extreme degree of crushing and condensation found in many hornblende schists of Manhattan island.

These facts alone seem to me decisive on the question of the genesis of the latter.

APPALACHIAN BELT

Many of the hornblende schists which occur in abundance along our eastern coast must be closely allied to that of Manhattan island. In New Hampshire the origin of a hornblende schist has been attributed to alteration of a diorite.* In the collection at Columbia University a specimen of hornblende slate from Woodbury, Connecticut, is identical with that of this island. A specimen from Pennsylvania of finely fibrous black hornblende schist of silky luster (specific gravity, 3.027), labeled "West side of the Schuylkill river, 2 miles north of Girard avenue, Philadelphia," closely resembles that of our locality at West One hundred and thirty-fifth street, with the same characteristic crumbling texture. In a letter dated May 1, 1899, from my friend, Mr Theo. D. Rand, recently deceased, of Radnor, Pennsylvania, he stated concerning outcrops in that vicinity: "We have some interesting diabases, diorites altered into hornblende schists (dikes) and gabbros." Doubtless the series of crystalline rocks in vicinity of Philadelphia includes the same hornblende schist whose genesis is under consideration.

Similar schists are distributed further south along the Appalachian belt, through Virginia, the Carolinas, and Georgia; but one tract northwest of Baltimore, carefully studied by G. H. Williams,† offers some important points of difference which may intimate the initial history in development of our own schist. There a hypersthene gabbro ("the original type") passes into a greenish gabbro diorite, massive or schistose (analysis XXIII). The latter form, described as anorthite amphibolite, diorite schist, or amphibole schist, was composed of fibrous green hornblende, possessing a satiny luster, recognized as "the paramorphic product of the pyroxene," and of opaque white feldspar, anorthite. A specimen in the collection at Columbia University of the laminated hornblende schist from White's granite quarry at Baltimore is identical in satiny luster and general character with that of Manhattan island and of New Rochelle, New York. The chief differences in constitution of these diorite schists and our own are interesting and significant.

First. There is a general abundance of feldspar, anorthite; somewhat inferior specific gravity, 2.996 to 3.069; and passage into pyroxenic rock.

Second. There is a rarity of quartz, that mineral occurring only as minute inclusions and in veins associated with granite and pegmatite.

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* G. W. Hawes, Geol. of N. H., vol. iii, pt. iv, 1878, p. 231.

† U. S. Geol. Survey, Bull. no. 28, 1886, p. 49; also Johns Hop. Univ. Circ., no. 30, 1884.

Third. There is a limited amount of alteration resulting from pressure, as explained by Williams, who states that

"Only such rocks within the Baltimore gabbro area exhibit a schistose structure as have their pyroxene *entirely* replaced by green fibrous hornblende. By no means all of the plagioclase hornblende rocks, however, are schistose. The larger proportion of these areas are as massive as the gabbros. . . The rocks of the Baltimore gabbro area do not exhibit in their individual mineral constituents the effects of having been subjected to an enormous strain. The bending and breaking of crystals and the disturbance of their optical constants, which is so often observed in the rocks of some much more contorted regions, are here rarely noticed. . . The very fact that the pressure has not been as great as in certain other more disturbed areas may perhaps itself be sufficient to account for the abundant masses of the unchanged pyroxene rock occurring in the midst of its hornblendic derivative."

It may be added that the same close association of biotitic schists attends the hornblende rocks at Baltimore* as those on Manhattan island. Both their resemblances and their very differences in the two regions only bring out the more satisfactorily the fact of their common origin.

Serpentine Outcrops

The decomposed and hydrated form of ferromagnesian silicate, distinguished as serpentine, is also found in this district, and its genesis is interwoven with that of the amphibole schists. Its direct derivation from them is plainly shown by constant accompaniment and close intermixture, as recognized by Dana, Gratacap, F. J. H. Merrill, and others, though referred by Dana back to antecedent limestone.†

Only one area of importance occurred, which occupied several acres in a long belt, with a width of 3 to 30 rods,‡ between West Fifty-fourth and Sixty-third streets, from Tenth avenue to the Hudson river (figure 9). On the southwest it was in contact with the most extensive boss of gneissoid granite on the island, whose conversion from a gneiss into that form by pegmatization seems to have been simultaneous with that of the hornblende rock into actinolite schist. In regard to this outcrop, now inaccessible, it may be of interest to consider some details taken from old field notes, recorded during many visits in 1878. A large part of its area occupied a basin-like depression, with swampy bottom and deeply gullied sides, about Fifty-eighth street, which seemed to have been excavated in the softer material during some ancient time by a small stream running westward to the Hudson. The bosses of tough rock had been

* G. H. Williams, op. cit., p. 36.

† Am. Jour. Sci., vol. xx, 1880, pp. 30–32.

‡ Mather, op. cit., p. 461.

also swept clean, scored and rounded by glacier action, so that fresh surfaces were everywhere exposed for examination. A section from Fifth avenue westward along Fifty-eighth and Fifty-ninth streets, across the prevalent northeast strike in this vicinity, presented the following features:

From Fifth to Sixth avenues the predominant rock was gray micaceous gneiss, with many thin intercalations of mica schist and seams of granitoid gneiss, on the western side of a broad anticlinal fold; dip, 70° > northwest. Near Fifth avenue rose a thick bed of slaty black hornblende gneiss, highly epidotic, some layers pure epidosite, 2 to 3 inches thick. Near Sixth avenue a bed of tremolite schist about 40 feet thick was intercalated, with the same westward dip, followed by micaceous gneiss and granitoid gneiss.

We may here digress to consider another parallel section of the same sheet by passing only a hundred yards along the strike to the southwest, between Fifty-seventh and Fifty-eighth streets.

At Fifth avenue occurred layers of micaceous gneiss and mica schist, greatly plicated; strike, north 63° east, with dip 60° north, some becoming north 43° east, with dip 80° east, with occasional thin granite seams on the east slope of a broad anticlinal fold at Sixth avenue.

Between Sixth and Seventh avenues the center of the fold near the middle of the block, was occupied by a fine grained, compact micaceous gneiss (quartzose, with black and white micas), inclosing a sheet of hornblende schist, 2 feet thick, about 100 feet from Seventh avenue; dip, 80° > west.

From Seventh to Eighth avenues, on the west slope of the anticline, fine and coarse gray gneisses prevailed, sometimes garnetiferous and inclosing a very thin sheet of hornblende schist about half way and a sheet of pegmatitic granite at Broadway.

Comparison of these two sections of the same bed at Fifty-seventh and Fifty-ninth streets establishes two important facts:

First, that the two thin sheets of hornblende schist in the Fifty-seventh Street section are the tapering southern edges of two thick beds in the Fifty-ninth Street section; the one of hornblende gneiss, the other of tremolite schist—that is, the latter is but an altered form of hornblende schist.

Second, that the hornblende rock does not lie on a single horizon in the Manhattan schists, but on at least two planes, about 500 feet apart on a section of the strata.

Continuing the main section along Fifty-eighth and Fifty-ninth streets, the same westerly dip prevailed to Twelfth avenue and the Hudson river.

FIGURE 9.—*Tremolite and Serpentine Tract, with associated Gneisses and Beds of Hornblende Schist.*
Locality, Eleventh avenue and West Fifty-ninth street.

From Sixth to Eighth and Ninth avenues thinly bedded micaceous gneiss, highly quartzose, with thin alternations of compact gneiss and mica schist.

From Ninth avenue the same gneiss for about 250 feet, with micaceous layers, often wavy, followed by four layers of slaty hornblende schist, about 100 feet, separated by thin sheets of coarse granitoid gneiss ; then gray gneiss, with equal amounts of white and black micas, as far as Tenth avenue, inclosing a thick bed of coarse pegmatite carrying large crystals of orthoclase and muscovite.

From Tenth avenue micaceous gneiss, 250 feet; mica schist, nearly 80 feet; blackish green tremolitic serpentine (spotted with greenish gray altered actinolite), about 40 feet, inclosing thin sheets of tremolite schist; hydrated tremolite schist ("hydrous anthophyllite"), at least 60 feet, inclosing many layers and amorphous masses of serpentine, ophicalcite, compact tremolite rock, and sometimes asbestus. Strike undisturbed; dip 70° west.

From Eleventh avenue, again the micaceous gneiss, inclosing one thin layer of mica schist, as far as the shore of the Hudson river, about Twelfth avenue; same strike and dip.

The section has been presented in this detail to explain the uniform continuity of the bedding, those of tremolite, serpentine, etcetera, occupying a position toward the upper part of the stratum, so far as present in the section; also the frequent intercalation of hornblende schists and granite sheets. The layers of hydrous magnesian rocks between Tenth and Eleventh avenues were plainly derivatives from an original heavy bed of actinolite schist, about 100 feet. If a reversed fold, common on the island, occurred here, between Ninth avenue and the river, this bed of actinolite schist between Tenth and Eleventh avenues was but a facies of the thick bed of hornblende schist between Ninth and Tenth avenues; but in the absence of any evidence of such a fold, I was more inclined to the view that this actinolitic bed and its derivatives corresponded to the upper hornblendic layer, that which occurred as a tremolite bed at Fifty-ninth street and Sixth avenue.

As for the purest rock serpentine here, it was but a serpentinized tremolite rock, such as classed by von Drasche under "serpentine-like rocks."* On account of its softness, however, such portions of the bed had undergone a deeper decay and subsequent scoring out by glacier action. Doctor Gale states that he found the more resistant "anthophyllite rock" occupying "a series of conical hills—some five or six—in a northerly and southerly direction."†

* Tsch. min. u. pet. Mitth., 1871, p. 1.
† Mather, op. cit., pp. 92, 94.

No chemical analysis has ever been recorded * of the massive serpentine-like rock of this locality, the attention of mineralogists and chemists having been mainly attracted to the "hydrous anthophyllite," which, as first shown by Dana,† represents the original actinolite in condition of hydration, preceding the process of serpentinization. The first three of the following analyses exhibit the process of this change:

XXXV. "Hydrous anthophyllite" (mean of two analyses). West Fifty-ninth street. Smith and Brush.

XXXVI. "Asbestiform mineral found associated with chlorite. New York island." Doctor Thomson.

XXXVII. "Hydrous anthophyllite." Boulder found at East Forty-ninth street, near Madison avenue. C. A. Joy.

XXXVIII. Serpentine. Aqueduct shaft 26. Catlett.

	XXXV.	XXXVI.	XXXVII.	XXXVIII.
SiO_2	58.33	54.98	46.43	39.92
Al_2O_3	Trace	1.56	....	.08
Fe_2O_3	....	9.83	....	.50
FeO	8.76	....	9.38	....
MnO	....	1.20	1.38	....
CaO	....	....	5.06	.90
MgO	29.34	13.38	28.80	42.52
K_2O	Trace	6.80	....	CO_2 1.64
Na_2O	.88	....	....	....
H_2O	2.26	11.45	8.58	14.62
	99.57	99.20	99.63	100.18

At West Fifty-ninth street a portion of the "hydrous anthophyllite" layer was occupied by irregular greenish masses, made up apparently of serpentine, calcite, actinolite, tremolite, chlorite, and talc, which have been described by S. Akerly (1819), L. D. Gale (1839), I. Cozzens (1843), and Mather (1843). More recently, Gratacap has described the "seam-like bands of ophicalcite of irregular thickness, expanding and contracting, and sporadically occupied nests or spots inclosed in the surrounding rock; the bands rising and falling as if they had undergone plication, as in the folded gneiss layers of the island." ‡ Toward Sixty-third street the amphibolite became richer in talc, associated with much chlorite, passing in part into steatite. Along the east side of the bed, near its contact with the gneiss, a layer of quartz rock attracted the attention of the earlier observers—perhaps simply a more quartzose layer of the gneiss.

* The analysis of serpentine attributed by Newland to Doctor Thomson is evidently, by some oversight, an inexact copy of Joy's analysis (xxxvii) of "hydrous anthophyllite."

† Am. Jour. Sci., vol. xx, 1880, p. 31.

‡ Am. Jour. Sci. (3d series), vol. xxxiii, 1887, p. 373.

Gale has also recorded the occurrence of ophicalcite in beds at West One hundred and fifty-seventh street, about 100 feet west of Tenth avenue, exactly on the line of strike of the actinolite schist on West One hundred and fifty-fifth street. Indications of other outcrops of serpentine have been since discovered at East One hundred and twenty-third street and Lexington avenue, and at Aqueduct shaft number 26, both in coarsely crystalline dolomite. Of the latter it is stated, "It plainly originates through the hydration of a white monoclinic pyroxene . . . accompanied with the formation of abundant secondary calcite."* Its analysis has been given (XXXVIII) in the preceding table and differs sharply from the others by its lack of iron oxides.

In the chemical reactions which have attended the latest change in the antecedent actinolite beds, serpentinization, there has been an obvious succession: First, hydration and bleaching as tremolite, with removal of iron oxide or its partial recombination with alumina in chlorite; second, the development of serpentine, or sometimes talc, with utter excretion of the lime of the original amphibole and its concentration in rude, layer-like deposits, almost massive, of ophicalcite. The true ophicalcite, familiar to the petrographer, is a rock of very different character and origin, whose serpentinization was preceded by the saturation of a crystalline limestone with amphibole or pyroxene. Its discrimination from calciferous serpentine derived from alteration of gabbro has already been drawn; † but we have here, on Manhattan island, an instance of the latter which has acquired an imitative structure which bears some resemblance to that of a true ophicalcite. The essential distinction between the two is that in true ophicalcite or ophidolomite the calcite or dolomite is primary—a survival of grains of the original limestone; in the ophicalcite of Manhattan, secondary, a chemical deposit in interstices of cellular serpentine; the structural evidences correspond.

Summary of Conclusions

REVIEW OF THE GENETIC HYPOTHESES

The following are my chief conclusions as to the three hypotheses of derivation of the hornblendic rock of Manhattan island:

First, from alteration of ferruginous sediments. It differs from them widely in chemical composition—less silica, greater amount of iron oxides, and excess of alumina; also in structure and form. Compared with the

* G. P. Merrill, Proc. U. S. Nat. Mus., vol. xii, 1889, p. 598.

† Roth: Op. cit., vol. ii, p. 190 et seq.

products of alteration of volcanic tuff, it contains less silica, but the structural differences are still more decisive against this view.

Second, from amphibolization of limestone. Incipient stages of this process are indeed shown in the limestones of the island, but, from the paucity of the latter in alumina and iron oxides, these changes have never resulted in production of hornblende or augite. The composition of amphibole known to be of that origin from other regions may approximate that of Manhattan island, but the solution of the question must be sought in other considerations.

Third, from alteration of basic igneous intrusions. This appears established by the correspondence of the hornblende rock in chemical composition to basic igneous rocks and to hornblende schists of that derivation, by identity of its hornblende constituent with that found in volcanic rocks, by the discovery of many apophyses, isolated or in groups, and other structural features, and by the survival of products of contact alteration. The absence of pyroxene and of dike-like intersection of the associated gneisses may be well explained by the extent of shearing and metamorphism.

These hornblendic schists then represent the most ancient group of intrusions into the Manhattan series, probably both as dikes and sills and mainly along one or two horizons, about 500 feet apart. In the larger sheets the trap was apparently porphyritic, with holocrystalline groundmass, of extreme basic composition and probably rich in pyroxene. While no definite evidence appears of the survival of that mineral in any rocks of the island, the remnants of phenocrysts point to the gabbro-like character of these ancient dikes, and perhaps to their issue as a fringe to the now well known center of eruption, 30 miles north, near Croton point*—or more likely, I think, at an independent center of still greater antiquity in the Manhattan region.

During the initial shearing the ready flow of the basic material has produced extensive folding and crumpling of sheets, perhaps assisted in some cases by downward crushing of upright dikes and possibly by rolling out of thick laccolitic masses. This was further advanced, even to minute corrugation of laminæ, by the softening which attended the beginning of pegmatization.

But my latest consideration of the phenomena suggests that the basic material, originally injected probably in continuous thin sheets along only one or two planes, has moved freely under the intense pressures, squeez-

* In 1865 Dr Hermann Credner published his "Geognostische Skizze der Umgegend von New York" (Zeits. d. D. geol. Ges., vol. xvii, 1865, pp. 388–398), in which he did not recognize the presence of amphibole rocks on the island, though from several miles to the north up to the vicinity of Peekskill he records the passage of hornblende gneiss and schist into syenite and hypersthenite.

ing back and forth along these division planes of the more rigid strata, here pinching out and apart and there thickening up into larger isolated lenses, as now found along the strike. If this be true, the present thick beds are generally, at least, only the result of such rolling together of masses of the ancient paste and not of original intrusion. Even the apparent apophyses also may be those of secondary injection along foliation planes during the new condition of fluidity assumed during shearing and metamorphism.

By saturation with quartz and addition of a little orthoclase, consolidation took place; so that during continued orogenic movements and intrusion of pegmatite dikes these lenses of schist acted as rigid masses, suffering fracture, dislocation, and sometimes mutual attrition along faults to a friction breccia.

Comparison with basic rocks in the neighboring region, of whose intrusive character there is no question, shows such a trap in all stages of alteration, from a gabbro-like diorite to hornblende schist and gneiss, identical with those of this island, even to microscopic peculiarities. Similar series of ancient intrusions occur in the tracts of crystalline rocks along the entire Atlantic belt, in whose metamorphism the earlier phase is well illustrated in the pyroxenic gabbro-diorite series of Maryland, and one of the latest in the hornblende schists of Manhattan.

PARAGENESIS OF MINERALS.

Finally, the facts above presented impress some conclusions concerning the paragenesis of three minerals.

First, the particular significance in the Manhattan series of the presence of hornblende. Notwithstanding a good proportion of all its required bases in the composition of the gneisses of the island (analyses I and II), further confirmed by the general diffusion of biotite, and notwithstanding the wide play of changing conditions which has prevailed during alteration of the old sediments into the present gneisses, not a trace of hornblende has been anywhere developed. Its occurrence has been no accident of metamorphism, but is found exclusively confined to the thin intercalated sheets now shown to represent injected igneous rock.

Second, the generation of epidote only under conditions of pressure and strain. It has been shown to be the invariable accompaniment of extreme folding and minor crumpling of the hornblende schist, its mere presence bearing the same testimony as the strain shadows, under the microscope, of the associated minerals.

Third, the secondary character of the quartz, constantly found in close intermixture with the hornblende. While the quartz diorite and pegma-

tite, in dikes of this region, probably indicate the two materials usually corresponding in segregation from a common magma of neutral composition, it is a curious anomaly to find in the former, the basic extreme, as much quartz (40 to 50 per cent near Harrison, according to H. Ries) as in the acid pegmatite ; but the universal association of the hornblende schists with gneisses saturated with pegmatite of the earlier diffusion, the later intersection, both of gneisses and these schists, by abundant seams and lenses of quartz, and the invariable revelation through its optical characteristics, that this was the last comer among the minerals of the hornblende rock, together testify to the secondary character of the quartz disseminated through the great tracts of quartz diorite and dioritic gneiss near Harrison, through the coarse diorites and amphibolites at New Rochelle, Rye and vicinity along the Sound, and through their sheared equivalents the dioritic and hornblende schists and gneisses of Westchester county and of Manhattan island. All are but forms of a silicified diorite.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 14, PP. 495-609, PLS. 64-65 MARCH 31, 1904

PROCEEDINGS OF THE FIFTEENTH ANNUAL MEETING, HELD AT WASHINGTON, D. C., DECEMBER 30 AND 31, 1902, AND JANUARY 1 AND 2, 1903, INCLUDING PROCEEDINGS OF THE FOURTH ANNUAL MEETING OF THE CORDILLERAN SECTION, HELD AT SAN FRANCISCO, DECEMBER 30 AND 31, 1902

HERMAN LE ROY FAIRCHILD, *Secretary*

CONTENTS

Session of Tuesday, December 30

The Society was called to order by the President, N. H. Winchell, at 10 o'clock a m, in the room of the Division of Illustrations, on the

second floor of the United States Geological Survey building, where all the sessions of the meeting were held except the evening session of this day.

Dr Charles D. Walcott, Director of the United States Geological Survey, made an informal address of welcome, to which the President responded.

The report of the Council was called for and was presented by the Secretary, in print, as follows:

REPORT OF THE COUNCIL

To the Geological Society of America,
in Fifteenth Annual Meeting Assembled:

The Council congratulates the Fellows of the Society on its sustained prosperity, which allows this report, apart from the reports of the officers, to be little more than a formality. The stated meeting of the Council was held with the meeting of the Society at Rochester, but a quorum was not present at Pittsburg, and no special meetings have been held.

Secretary's Report

To the Council of the Geological Society of America:

Meetings.—The records of the Fourteenth Annual Meeting, held in Rochester, December, 1901, and the Fourteenth Summer Meeting, held in Pittsburg in June, 1902, will be found in the proceedings brochures of the Bulletin, volumes 13 and 14.

Membership.—Since the last report three Fellows have died—Alpheus Hyatt, James E. Mills, John W. Powell. The fourteen candidates elected at the winter and summer meetings all qualified, and the present enrollment is 256, the largest in the history of the Society. Only one name is liable to be dropped for non-payment. Five nominations are now before the Society, and several are awaiting action by the Council.

Distribution of Bulletin.—At this date 352 pages of volume 13 have been mailed. During the past year the irregular distribution of the Bulletin has been as follows: Complete volumes sold to the public, 49; to Fellows, 26; 41 brochures have been sent to fill deficiencies, 24 have been sold to the public and 12 to Fellows, and one has been donated. Two copies of volume 12 have been donated and three bound for use of the officers and the library. The Fellows and the subscribers to the Bulletin should be reminded that claims for brochures lost in the mails should be filed promptly.

Bulletin sales.—Receipts from sale of the Bulletin during the past year appear in the following table:

Receipts from Sale of Bulletin, December 1, 1901, to December 1, 1902

	Complete volumes.			Brochures.			Grand total.
	Public.	Fellows.	Total.	Public.	Fellows.	Total.	
Volume 1.	$15 00	$9 00	$24 00	....	....	....	$24 00
Volume 2.	20 00	9 00	29 00	$ 80	$ 45	$1 25	30 25
Volume 3.	15 00	8 00	23 00	1 15	....	1 15	24 15
Volume 4.	20 00	3 50	23 50	1 45	....	1 45	24 95
Volume 5.	15 00	4 00	19 00	50	....	50	19 50
Volume 6.	30 00	4 00	34 00	50	70	1 20	35 20
Volume 7.	30 00	4 00	34 00	39	....	39	34 39
Volume 8.	25 00	4 00	29 00	1 30	....	1 30	30 30
Volume 9.	25 00	4 00	29 00	2 40	....	2 40	31 40
Volume 10.	25 00	4 00	29 00	30	....	30	29 30
Volume 11.	35 00	4 50	39 50	3 95	75	4 70	44 20
Volume 12.	210 00	4 00	214 00	1 95	3 15	5 10	219 10
Volume 13.	125 00	....	125 00	....	90	90	125 90
Volume 14.	30 00	....	30 00	....	....	....	30 00
	$620 00	$62 00	$682 00	$14 69	$5 95	$20 64	$702 64
Index......	26 25	2 25	28 50	....	....	....	28 50
	$646 25	$64 25	$710 50	$14 69	$5 95	$20 64	$731 14

Receipts for the fiscal year................................	$731 14
Previous receipts, to November 30, 1901.................	6,044 56
Total receipts to date..	$6,775 70
Charged and uncollected......................................	51 25
Total Bulletin sales to date..................................	$6,826 95

Bills for the copies of volume 13 to permanent subscribers have not been sent. These will add about $250 to the amount of sales.

During the 12 years covered by Bulletin sales the loss to the Society by uncollected bills is only $5.61, due to three items, which have now been crossed from the books and not included in the above table.

Exchanges.—The list of exchanges remains the same as in the last report. It includes 87 addresses.

Expenses.—The following table gives the cost of administration and distribution of the Bulletin from the Secretary's office during the past year:

EXPENDITURE OF SECRETARY'S OFFICE DURING THE FISCAL YEAR ENDING NOVEMBER 30, 1902

Account of Administration

Postage and telegrams..	$21 30	
Expressage..	25	
Printing (including stationery)................................	130 90	
Meetings (not included in printing)........................	2 35	
Total..		$154 80

Account of Bulletin

Postage	$69 00	
Expressage and freight	74 86	
Wrapping material	40	
Collecting of checks	4 40	
Total		148 66
Total expenses for the year		$303 46

Respectfully submitted.

H. L. FAIRCHILD,
Secretary.

ROCHESTER, N. Y., *December 20, 1902.*

TREASURER'S REPORT

To the Council of the Geological Society of America:

The Treasurer herewith submits his annual report for the year ending December 1, 1902, along with other statements of general interest.

One Fellow has been dropped from the roll for non-payment of dues, while only eight (8) are delinquent for two years and eighteen (18) for one year. This is the smallest delinquent list in the Society's history.

Of the eleven (11) Fellows elected at the June meeting in Pittsburg, five (5), viz., E. R. Buckley, W. S. T. Smith, W. C. Mendenhall, George D. Louderback, and A. W. G. Wilson, have been enrolled for life by the payment of $100 commutation fee, thus increasing the entire number of Life Commutations to fifty-eight (58).

The price of first-class investment securities has ruled so high during the year that the committee appointed at your last meeting to secure additional permanent investments for the publication fund has deemed it unadvisable to purchase. Hence the funds that would have been invested have remained on deposit with the Security Trust Company of Rochester, New York, where the Society gets four (4) per cent interest on monthly balances, a rate higher by more than 1 per cent than could have been secured from the purchase of government bonds or other high-class securities.

The interest item of $151.83 has accrued from this source.

The number (15) of uninvested commutation fees now amounts to $1,500, and some action should be taken to invest this sum for the publication fund during the coming year.

The amount of invested funds is the same as last year, $4,300.

The Society has been receiving dividends at the rate of 6 per cent on the ten (10) shares of stock owned in the Iowa Apartment House Company of Washington, D. C., and the Treasurer thinks it would have been wise had more of this stock been purchased, as recommended in his last report.

Statement of Receipts and Expenditures

RECEIPTS.

Balance in Treasury November 30, 1901			$3,600 32
Fellowship fees 1900 (4)	$40 00		
" " 1901 (22)	220 00		
" " 1902 (169)	1,690 00		
" " 1903 (1)	10 00		
		$1,960 00	
Initiation fees (14)		140 00	
Life commutation fees (5)		500 00	
Interest on investments:			
Tioga Township Kansas Bonds	$70 00		
T. K. & F. R. R. bonds	18 00		
Texas Pacific R. R. bonds	100 00		
Iowa Apartment House Co. stock	48 11		
Deposits in Security Trust Co.	151 83		
		$387 94	
Sales of publications		731 14	
Credit on account of check issued in 1894 to Standard Engraving Co. and which was never presented for payment, thus correcting difference in bank account and the Society's books		1 05	
Postage repaid into treasury by Bailey Willis and J. A. Holmes		0 75	
			$3,720 88
Total amount of receipts			$7,321 20

Amount of receipts brought forward				$7,321 20

EXPENDITURES.

Administration, library and distribution of Bulletin—				
Secretary's office:				
Administration	$154 80			
Bulletin	148 66			
Allowance (traveling and clerical expense)	500 00			
		$803 46		
Treasurer's office:				
Postage and exchange		23 25		
Editor's office:				
Allowance for personal and office expenses		250 00		
Librarian's office		9 28		
			$1,085 99	
Photograph Account		$16 85	16 85	
Publication of Bulletin:				
Printing		756 56		
Engraving		358 71		
			$1,115 27	
				$2,218 11
Balance in treasury November 30th, 1902				$5,108 09

The interest received from all sources foots up $387.94, as against $383.24 for last year.

The financial status of the Society, and also the receipts and disbursements for the past year up to December 1, 1902, are embodied in the preceding balance sheet. It should be noted that the large balance in the treasury contains $1,500 which belongs in the publication fund, and that large bills for later printing of volume 13 will be drawn against it.

Respectfully submitted.

I. C. WHITE,
Treasurer.

MORGANTOWN, W. VA., *December 10, 1902.*

EDITOR'S REPORT

To the Council of the Geological Society of America:

By reason of the absence of members in the field, and consequent difficulty in getting proof returned, it has been impossible to complete volume 13 before the close of the year; hence only a preliminary statement can be made by the Editor.

The proceedings of the Rochester meeting is the only brochure which remains to be printed at this writing, all the other papers, aggregating some 400 pages, having been printed and distributed. The Rochester proceedings are now in galleys, and it can be estimated that the volume will contain from 475 to 500 amply illustrated pages. An interesting feature of volume 13 will be a carefully prepared catalog of all photographs belonging to the Society, which will be found convenient for reference by members of the Society and the interested public.

No definite statement of cost can be given until the volume is completed, and this and other statistical material will appear in a future report to the Council.

All the manuscripts of volume 14 thus far received by the editor are in the printer's hands, and its publication will be rapidly accomplished as soon as volume 13 can be disposed of.

	Average. Vols. 1-10.	Vol. 11.	Vol. 12.	Vol. 13.*
	pp. 544. pls. 26.	pp. 651. pls. 58.	pp. 538. pls. 45.	pp. 583. pls. 58.
Letter-press	$1,465 14	$1,815 56	$1,445 73	$1,647 12
Illustrations	200 40	373 68	414 80	477 27
	$1,665 54	$2,189 24	$1,860 53	$2,124 39
Average per page	$3 23	$3 36	$3 45	$3 64

* These figures for volume 13 were inserted in the Editor's report since the report of the Council was submitted, thus making it complete for the record.

The following is a reasonably correct analysis of the contents of volumes 7 to 13, inclusive:

Divisions.	*Vol. 7. Pages.*	*Vol. 8. Pages.*	*Vol. 9. Pages.*	*Vol. 10. Pages.*	*Vol. 11. Pages.*	*Vol. 12. Pages.*	*Vol. 13. Pages.*
Areal geology	38	34	2	35	65	199	143
Dynamic geology	3	24	85	24	110	23	18
Economic geology	4	14	16	28	7	5	17
Glacial geology	105	98	138	96	21	55	1
Historical	..	..	..	16	46	..	20
Memoirs of deceased members	28	8	12	27	60	2	31
Official matter	56	69	54	72	59	58	157
Paleontology	123	58	64	68	188	5	43
Petrology	40	43	44	59	54	24	11
Physiographic geology	53	5	..	37	10	53	24
Relation of geology to pedagogy	12	..	..	..	..	..	...
Rock decomposition	74	26	17	9	..	16	...
Stratigraphic geology	21	67	28	62	31	98	117
Terminology	1	..	..	1	..	..	...
Total	558	446	460	534	651	538	583

JOSEPH STANLEY-BROWN,
Editor.

NEW YORK, *December 15, 1902.*

LIBRARIAN'S REPORT

To the Council of the Geological Society of America:

The list of additions to the Library for the year ending June 1, 1902, was, early in June, compiled and transmitted to the Secretary for publication in the Bulletin. It will shortly appear in the closing brochure of volume 13.

So far as the Librarian is aware, there are no rules governing the drawing of books from the Library by the Fellows of the Society. It is obviously desirable that there be such, and the Librarian would suggest the adoption of rules governing the payment of transportation charges, the length of time during which books may be retained, the penalty to be exacted for exceeding this limit, if any; the immediate acknowledgment of the receipt of books forwarded from the Library, and any other regulations that may seem desirable to the Society.

The Librarian would be glad of suggestions as to how the Library may be made of greater use to the Society. There are files of many publications on the shelves, from 1890 or thereabouts to date, which it would seem should be useful to many, in spite of the necessary payment of transportation charges. The list of such publications can be readily ascertained by inspection of the List of Exchanges published annually in the Bulletin.

The expenses of this office for the past year are as follows:

To postal cards and printing	$4 25
stationery and express charges on same	2 20
express charges on publications	1 75
postage	1 08
	$9 28

Respectfully submitted.

H. P. CUSHING,
Librarian.

CLEVELAND, OHIO, *December 10, 1902.*

On motion of the Secretary, it was voted to defer consideration of the Council report until the following day.

As the Auditing Committee to examine the accounts of the Treasurer, the Society elected J. S. Diller and Arthur Keith.

ELECTION OF OFFICERS

The result of the balloting for officers for 1903, as canvassed by the Council, was announced by the President, and the officers were declared elected as follows:

President:

SAMUEL F. EMMONS, Washington, D. C.

First Vice-President:

ARNOLD HAGUE, Washington, D. C.

Second Vice-President:

H. S. WILLIAMS, New Haven, Conn.

Secretary:

H. L. FAIRCHILD, Rochester, N. Y.

Treasurer:

I. C. WHITE, Morgantown, W. Va.

Editor:

J. STANLEY-BROWN, Washington, D. C.

Librarian:

H. P. CUSHING, Cleveland, O.

Councillors:

R. D. SALISBURY, Chicago, Ill.
J. E. WOLFF, Cambridge, Mass.

ELECTION OF FELLOWS

The Secretary announced that the candidates for fellowship had received a nearly unanimous vote of the ballots sent, and that they were elected as follows:

George Irving Adams, A. M., Sc. D., Washington, D. C. Geologist, U. S. Geological Survey.

Joseph Barrell, Ph. D., South Bethlehem, Pa. Assistant Professor of Geology, Lehigh University.

Joshua William Beede, Ph. D., Bloomington, Ind. Instructor in Geology, Indiana University.

Charles Kenneth Leith, Ph. D., Madison, Wis. Assistant Geologist, U. S. Geological Survey; Assistant Professor of Geology, University of Wisconsin.

Willet Green Miller, M. A., Bureau of Mines, Toronto, Canada. Provincial Geologist of Ontario.

No new business was presented. The President called for the necrology, and the following memoirs of deceased Fellows were presented:

*MEMOIR OF ALPHEUS HYATT**

BY W. O. CROSBY

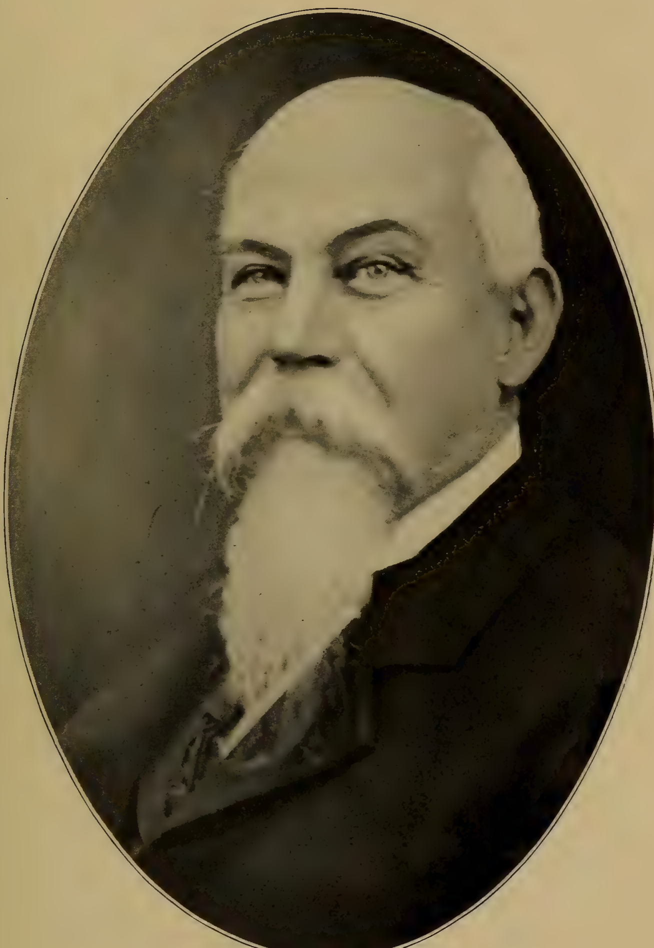
In the death of Professor Alpheus Hyatt the cause of science has met with a double loss—the loss of a careful investigator, whose work enriched the world's store of scientific knowledge, and of a science teacher, who, in teaching others to teach, spread the love and appreciation of science broadcast. Along both these lines his work was of the best, and bore that stamp of vitality and originality which was characteristic of the man.

He was an investigator who labored with painstaking zeal in the field of research, but always with eyes on the bounding horizon. To extend this horizon by the discovery of new truths was one of the dearest objects of his heart, and one which he was privileged to attain. The philosophical results of his work as an investigator, sustained as they are by a foundation of well established facts, give it a value of the highest rank.

As a teacher, his enthusiasm for direct contact with nature and his energy in making this mode of study possible were such that to his pupils no other way of studying nature appears permissible and no obstacle which stands in the way of learning her lessons at first hand too difficult to be overcome.

Descended from an old Maryland family, he was born in Washington, D. C., April 6, 1838. He lived to be nearly sixty-four years of age, and

* Professor Crosby was not present when the memoir was called, and it was read at the session of Wednesday morning. It is, however, inserted here in its appropriate place.



Yours cordially
Alpheus Hyatt.

met his death suddenly while on his way to a meeting of the Boston Society of Natural History, January 15, 1902.

His youth fell in that fortunate time for students of nature in America when Professor Louis Agassiz was working and teaching in Cambridge, and it was Alpheus Hyatt's good fortune to be much under his instruction. He entered Yale in 1856, but after his freshman year left college to travel for a year in Europe. The career of a merchant, which his parents had intended for him, did not appeal to his tastes, nor did he take kindly to the study of law, which was next proposed to him. Finally, attracted to Cambridge by the fame of Agassiz, he entered the Lawrence Scientific School in 1858 and took up the study of geology. He graduated in 1862 and spent nine months of the following year in the Union army, from which he retired with the rank of captain. He then renewed his studies under Agassiz in Cambridge, and had for his associates many of the men who have since stood in the front rank of scientific workers in America. His most important work at this period was on the fossil cephalopods, to the study of which he was attracted by the valuable collections in the Museum of Comparative Zoology and concerning which he later published epoch-making papers.

His first work with Agassiz had awakened his mind to a new way of looking at natural objects. He himself says of it:

> "He gave me a pentacrinite or stone lily, a rather complex fossil, and told me to study it. This I thought to be easy work, so I took a stroll in the afternoon and thought little of it. Next morning he came up to my table and asked me what I had found. I had never studied from nature before, and began giving a very general description, saying that it was a fossil petrifaction, etcetera, and had what appeared to be the beginning of a stem. When I had got to this point he said in impatient tone, 'Stop! stop! you don't know anything about it. It is just what I expected. You haven't told me anything that you know. Look at it again and tell me something that you see for yourself.' I had faint book remembrances and had been relying on these. Taken all aback at this, I began to work. I thought about it all day, and dreamed about it at night. Next morning I began to tell him what I had found out, and before I was one-quarter through he stopped me, saying, 'That is good. But,' he added, 'you have not yet told me what I want.' With this he pointed to the side of the room, where star fishes, ophiurans, and sea urchins were kept, and told me to see what more he wanted. In this blind way, and with no further hint, I worked unsuccessfully for a long time. Then I found that I had omitted the most conspicuous point, the star-like appearance. Not knowing whether this was of importance or not, I timidly reported at the next interview this resemblance to the star fishes, and Professor Agassiz was satisfied. This burned into my mind the most important lesson of my life, how to get real knowledge by observation and how to use it by comparison and inference."

This method of acquiring knowledge was never more faithfully and judiciously used than by Professor Hyatt in conducting his researches;

and as a teacher he also possessed the power of awakening the mind of the beginner, and making of every pupil an investigator. The writer well remembers his own gropings in the dark in making the acquaintance of the carapace of the lobster, Professor Hyatt having placed this in his hands for an observation lesson, and the uplifting of soul that came with the consciousness that even the beginner may taste the joy of discovery.

In 1870 Professor Hyatt went to Salem, where he was associated with Messrs. Packard, Putnam, and Morse, his fellow-students under Agassiz, in the work of the Essex Institute and Peabody Academy; and here these four men, destined to be life-long friends, founded and for some years edited the American Naturalist.

In 1870 Professor Hyatt became custodian of the Boston Society of Natural History, and in the care and development of its museum entered upon one of the great works of his life. Here was a field where some of the advanced ideas with which his mind was teeming might be developed for the benefit of the public. In the language of a pupil and fellow-worker, he was keenly alive to the correlations existing both in the inorganic and organic world; it was his constant aim to demonstrate these reciprocal relations; his success in this work was such as to make this museum one the arrangement of whose material, both from a scientific and an educational point of view, challenges the progressive thought of the twentieth century; and nowhere, probably, have the principles of a natural classification based upon genetic relationship been more faithfully and admirably worked out.

From 1870 until 1888 Professor Hyatt also held the chair of zoology and paleontology in the Massachusetts Institute of Technology, and from 1877 the chair of biology in Boston University. At the time of his death he had been for many years in charge of the collection of invertebrate fossils in the Museum of Comparative Zoology at Cambridge, and was connected with the United States Geological Survey.

He was elected a member of the National Academy in 1875, and has held membership in many other scientific societies, both in this country and abroad. He was one of the founders and the first president of the American Society of Naturalists, and in 1898 he received the honorary degree of " Doctor of Laws " from Brown University.

From his college days until the end of his life Professor Hyatt was an active investigator. His researches were confined to certain orders of the Invertebrata, and all dealt in some degree with the problem of evolution. To elucidate these problems he used largely the shells of cephalopod molluscs. He made a special and prolonged study of the fossil cephalopods, and came to be recognized as the leading authority on that class. These studies led him to the neo-Lamarckian school of thought,

rather than to the Darwinian—evolution through the use and disuse of parts and other Lamarckian factors appealing to him more strongly than evolution through natural selection.

Some of his most important theories were, however, first fully worked out and illustrated in the memoir on the genesis of the Tertiary species of Planorbis at Steinheim. This investigation led him to Steinheim, where he made an exhaustive study of these shells as they occur in the successive strata of fresh water lakes, and, as perhaps the most striking result, he was enabled to demonstrate that—

"a single species, finding itself in an unoccupied field, proceeded with unexampled rapidity to fill it by the evolution of new species and many forms, all differing from each other, but all referable by intermediate varieties to the original type."

But the ammonites afforded Professor Hyatt material especially adapted to the kind of work in which he most delighted. In this marvelous group he worked out the correlation between the development of the individual and that of its class. In the span of life of a single creature he read the history of the race. This group also afforded a basis for his demonstration that new characteristics are acquired in response to the demand of necessity, and that these acquired characteristics are inherited at earlier and earlier stages in successive generations, thus accelerating the development of the race. These points are developed in a masterly manner in his paper on the phylogeny of an acquired characteristic, and oppose successfully the view that acquired characters can not be inherited.

Professor Hyatt not only recognized the successive stages in the life history of the individual and correlated them with the adult stages of ancestral groups, but he devised a complete nomenclature for these stages, which has gained general acceptance. The law of acceleration of development, known as the law of tachygenesis, and affording the key to the complex problems of phylogeny, was discovered almost simultaneously, but quite independently, by Hyatt and Cope in 1866, and in all his subsequent writings Hyatt was more than just in his cordial recognition of Cope's claim, finding, with the utter lack of jealousy which was one of his most prominent traits, additional gratification in the coincidence which made these two eminent collaborators warm friends for the rest of their lives. This great principle was rediscovered some years later by Würtenberger, and that it should come to be generally known abroad as Würtenberger's law could not naturally be regarded with quite the same degree of equanimity, although Professor Hyatt never doubted that time would right the error.

Among Professor Hyatt's most important contributions to the theory of organic evolution is his discovery and demonstration of the law of senile characteristics, the old age characters being regarded as prophetic of the adult characters of posterity. Although essentially a corollary to the principle of acceleration during the culmination of a group, applying it forward rather than backward, and forecasting the characters of undeveloped types, we find in this law of retardation during the degradation and extinction of a group a boldness and originality which clearly entitle it to distinct and special recognition.

Hyatt's system of classification takes account of all stages in the development of the individual, instead, as heretofore, of the adult characters only, and he may fairly be said to have founded a distinct school of paleontology, which one of his followers has fitly called the "Hyatt school."

Although Professor Hyatt was primarily and chiefly a paleontologist, his best and most enduring work, as we have seen, was accomplished along biologic rather than stratigraphic lines, and his contributions to the philosophic side of the science are second in value to those of no man. It may be noted in passing, however, that he also accomplished important results in pure biology, and in his studies on the polyzoa and sponges, and he was one of the first to recognize sponges as a distinct subkingdom of animals. In this connection also may be mentioned his beautiful explanation of the spiral shells of molluscs as due to the action of gravity.

The work which was nearest to his heart at the time of his death, and on which he had been engaged for several years, was the solution of certain problems in evolution presented by the land shells of the Hawaiian islands. One of these problems is the cause of variation when, apparently, physical conditions are essentially the same, suggesting an element of spontaneity which makes the organism more or less independent of the environment. He had studied exhaustively many thousands of these shells and had planned to visit Hawaii in the spring of 1902 to study the living animals and their relations to the habitat. He looked forward to the completion of this research as the crowning work of his life; but, incomplete as it now stands, his conception of it and his splendid enthusiasm are an inspiration to those who knew him best.

It is a matter for congratulation that a man so devoted to original work as was Professor Hyatt, a man of such unusual concentration of mind and habit of philosophical thought, should have given himself so largely to the cause of science teaching. He was happy in transmitting to others not only the knowledge he had gained, but something of his own spirit of investigation.

As early as 1870 he set on foot a movement which culminated in the founding of the Teachers' School of Science, a school free to all teachers, where work with specimens and direct contact with nature in field and laboratory should prepare them for the best work in the schools. Professor Hyatt was at the head of this school until his death, and under his wise management, and, above all, his strong personal influence, it has achieved a substantial success and become an important adjunct of the normal schools of eastern Massachusetts. The admiration and affection felt for him by the multitude of teachers who came under his influence was boundless. One of them has said:

"The wealth of his mind, the simplicity of his nature, the kindness and patience of his great heart placed him without a peer in the hearts of his pupils."

Another work which he did for teachers was to maintain at Annisquam, Massachusetts, during the summer months of several years a seaside laboratory where as many as could be accommodated might come for special work. In connection with this laboratory he conducted dredging expeditions along the eastern coast of New England. Such out-of-door work was always congenial to him, and in 1885 he went as far north as the strait of Belle Isle, doing important geological work on the west coast of Newfoundland, and thus supplementing earlier work by himself and others on the island of Anticosti. The Annisquam laboratory, it may be added, prepared the way for the biological laboratory at Woods Hole.

In his beautiful tribute to Professor Hyatt's life and work, Professor A. S. Packard well says that

"Whether we regard him as a man, a patriot, a fellow-student, a scientific investigator, an organizer of societies, of museums, or of methods of science teaching, his many sided life was a rare one. He was a promoter of scientific enterprises, one of the founders of a new school in the philosophy of biology, a master in paleontological methods, and endowed with rare powers of mental absorption and concentration and an unusual capacity for sound generalization."

Those who were so fortunate as to know Professor Hyatt personally will remember him as a man of sunny disposition and a beautiful cordiality of manner. His kindness and consideration toward his pupils were noteworthy. He was one of the most fair minded of men, unusually lacking in professional jealousy and broadly tolerant of the opinions of others.

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In the absence of the author, the following memoir was read by J. S. Diller:

MEMOIR OF JAMES E. MILLS*

BY J. C. BRANNER

James Ellison Mills, son of Doctor Preserved Brayton and Jane Lunt Mills, was born in Bangor, Maine, February 13, 1834, and died at San Fernando, Estado de Durango, Mexico, July 25, 1901. The boyhood of Mr Mills was spent at home, in the public schools and in the woods with crews of lumbermen working for his father. He prepared to enter Harvard College at the age of seventeen, but his father desired that he should first learn what he could of his country by traveling, and accord-

* For the data of this notice I am indebted chiefly to Mr Mills' surviving brother, Hiram Mills, of Lowell, Massachusetts.

James E. Mills

ingly in 1851 he went through lower Canada and the northern line of states to Minnesota, thence down through the states bordering on the Mississippi river to Saint Louis, across the middle states to Washington, and back to Maine, making more than 1,000 miles of the journey on foot and on horseback. In Minnesota he met and traveled with Doctor Carl Scherzer, of Vienna. By his advice he gave up the plan of entering Harvard College, but instead entered the Lawrence Scientific School in 1852. He spent part of his time under Louis Agassiz, both as student and as assistant, and graduated in 1857 *summa cum laude.* He continued as assistant to Professor Agassiz at Harvard until 1858, when he felt it his duty to turn his whole attention to the ministry. He accordingly began preaching in Brooklyn, New York, and in 1860 was ordained as a minister of the New Jerusalem church (Swedenborgian) and entered upon his duties of pastor of the society in Brooklyn, where he continued three years. His health failing, he gave up sedentary life and entered again on geological work. For two or three years he was engaged in exploring and locating coal beds on cape Breton and in Cumberland county, Nova Scotia. Until 1870 he had an office as consulting geologist in New York, and examined and reported on mining properties, among them iron deposits in Alabama, coal deposits in West Virginia, and oil deposits in western Pennsylvania. In 1868 he examined lead mines in Missouri and did geological work on the survey of the upper Mississippi, then being carried on by the government under General G. K. Warren. In 1869 he was mining manganese in Virginia. In 1869, 1870, and 1871 he was superintendent of Bradys Bend iron works, in western Pennsylvavia, and successfully located several oil wells in new territory. In 1871 and 1872 he was at the Vulcan iron works, in charge of the manufacture of steel rails, into which industry he introduced important improvements. From 1872 to 1879 he made Saint Louis, Missouri, his home. In 1873 he was vice-president of the Big Muddy Iron Company of Saint Louis. In 1877 he examined and reported on the mine La Motte and other lead properties in Missouri. In 1878 he examined and reported on gold mines in Rio Grande do Sul and in Minas Geraes, Brazil, South America. In 1879–'80 he was superintendent of the São Cyriaco Gold Mining Company in the diamond district of Minas Geraes, Brazil, but returned to this country in 1880. Since 1880 he has been consulting geologist and adviser of the capitalists interested in the Calumet and Hecla Mining Company, for whom he has examined and reported on several properties in the west and in Mexico. In 1880 he went to California to examine certain gold placer deposits, and while pursuing his work he devised a new method of sinking steel shafts to depths of 200 feet or more without removing the water until bed rock was reached,

and thus preventing surface water from following down the outside of the shaft. In connection with this work he began his study of the geology of the Sierra Nevada. This survey was begun for those who had employed him, but he continued it for many years at his own expense. In 1895 he went to Mexico and spent the last six years of his life in developing a mining property for the San Fernando Mining Company at San Fernando, Estado de Durango, where he died on July 25, 1901.

In 1861 he married Miss Mary Collier, of Brooklyn, New York; of their five children four survive him. After separation from his first wife he married, in 1894, Miss Jane Dearborn, of Orange, New Jersey, who was his constant and helpful companion during the last years of his life.

This is a bare outline of the life of our friend and fellow-member. At the end of this notice is given a list of his published papers on geological subjects. But neither this brief outline nor the list of papers affords a just estimate of the personal influence of Mr Mills on the men who knew him well; for that influence was moral rather than scientific.

In 1879–'80 I was intimately associated with Mr Mills. He was then the superintendent of the São Cyriaco Gold Mining company of Boston, with property on Rio do Peixe, near Serro, in the diamond regions of Brazil, and I was his assistant. In that capacity I had direct supervision of the engineering work under his charge and had also to act as his interpreter. Owing to his various relations with Brazilians and the necessity of communicating with them in the Portuguese language and through me, I had unusual opportunities for knowing his methods, his motives, and his character. Such relations were less enlightening in his case, however, than they would have been with many men, for Mr Mills was not a man who had anything in his character to cover up. What he was in public he was in private—an upright man in every sense.

One great service Mr Mills did in Brazil was, in the face of the customs of generations, to set up and maintain successfully a standard of honorable dealing between employer and employé. At the time of our residence in the diamond regions slavery was still in existence in Brazil, and he was frequently and forcibly reminded that the company's work could be done only by the use of slave labor. It was not expected that the company should own slaves, but that it would rent them of their Brazilian owners. Against the use of slave labor in any form Mr Mills set his face from the outset, though he fully realized that it would be very difficult to find enough free workmen. He was convinced, however, that the chief reason free labor was so difficult to find and more difficult to hold was because it was not well or promptly paid. His idea was to convince the employés that their wages would be paid promptly once a

week, and he believed that there would soon be no difficulty in finding all the labor he required; and this proved to be the case. The demands he placed on these men were more strict than they had ever been accustomed to, but they met these demands as soon as they realized that they were to be treated justly. He was scrupulously honest in dealing with his men; he always paid them promptly and never made or permitted any claims on their wages through the company's office.

Later, in Mexico, he met with many similar difficulties and with much opposition among all classes, but it is a great pleasure to know, and it is an honor to the profession, that he followed the same policy and met with the same success. One can hardly understand the importance and meaning of this policy unless he has had experience in dealing with people who live and die, generation after generation, under a system of oppression by debt, by social superiors, and by the pride of place and office.

His contributions to geological science are small. I never look at the list at the end of this paper without a sense of disappointment, for I know that he gathered and had at his command a vast amount of useful information upon geologic subjects. The bulk of his work, however, was done for private parties, and he always fully realized that information gained in this way was the property of his employers. Moreover, he never could have brought himself to publish anything for the sake of parading his information; it could only have been for the purpose of giving others the benefit of what he knew. To him geology was merely the expression of the laws of God, and was therefore always interesting, always worthy of the effort required to understand it, and it was for all mankind. He always acted as though he felt that what he had and what he knew (outside of what he controlled as an employé) was held in trust for the good—not of himself alone, but for the good of humanity.

On one occasion when I asked for the use of some of his books, he boxed them up and sent them to me with the request that after I had used them I should pass them on to whoever might require them.

When in 1890 Doctor Penrose undertook the study of the manganese regions of North America he found Mr Mills to be one of the few geologists of this country who at that time had and readily imparted valuable information regarding the manganese deposits of the United States. In the preface to his "Modern American Methods of Copper Smelting," Doctor E. D. Peters acknowledges "the valuable assistance of Mr J. E. Mills in connection with the geology of the Butte mining district." Mention is made of these instances as showing how free and helpful Mr Mills was with his knowledge, and even with his property.

His greatest piece of geologic work—that on the geology of the Sierra Nevada—has not yet been published. Begun about 1880 and continued up to the time of his death, it illustrates well his views of how a man of science should serve mankind. After some time spent in studying the geology of the Sierra Nevada at various points, he became convinced that the detailed study of a section across the mountains and embracing its type formations ought to solve at once most of its geologic problems. Such a piece of work, however, no business enterprise would think of undertaking, for it could not be counted upon to yield financial results, and no scientific institution felt able to undertake it. He therefore determined to do the work unaided, and all the time and money he could spare from other duties were thenceforth devoted to this investigation. Topographers and field assistants were employed out of his private funds, and an area of 160 square miles was mapped in great detail. The field notes were plotted on a scale of 1 to 2,400 and afterwards reduced to 1 to 12,000. In addition to this, an area of about 800 square miles was mapped on a mile to the inch scale. It should be remembered that this area lies across the high Sierras, chiefly in a forest-covered region that is very thinly populated and where field work is retarded by late and early snows.

A part of Mr Mills' results, obtained in his study of the sierras, are published in volume 3 of the Bulletin of this Society; but the bulk of them was not yet in shape for publication when he died. He was looking forward with pleasant anticipations to spending the last years of his life in making this piece of work his greatest contribution to geologic knowledge.*

Mr Mills was an inspiring teacher, and he had the art, by the use of simple and effective illustrations, of making things easy and at the same time impressive. He was a warm and tolerant friend, but he was likewise a warm and uncompromising enemy. As a geologist, he endeavored to be governed always by a judicial mind; but when he believed a thing he usually believed it very vigorously, and this trait of character sometimes led him into error and afterward caused him deep regrets. When he found himself in the wrong, however, he made haste to set himself right. He was a man of broad sympathies and was deeply interested in all kinds of social and economic questions.

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* Mr William Watson, of Quincy, California, has been Mr Mills' faithful assistant in all this work in the Sierra Nevada.

São Cyriaco gold mines, province of Minas Geraes, Brazil. (A report made to Messrs Riedel, Rader & Co., dated Rio de Janeiro, December 18, 1875, 8vo, 20 pp., 2 maps, and illustrations.) Appendix A, pp. 14–18, is upon geological details (n. d. or loc.).

Geological report on the mine La Motte estate, the property of Rowland Hazard, situated in Saint François and Madison counties, Missouri. New York, 1877 (51 pp. and maps).

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Quaternary deposits and quaternary or recent elevation of regions and mountains in Brazil, with deductions as to the origin of loess from its observed conditions there. *Amer. Geologist*, vol. 3, 1889, pp. 345–361; also separate.

Stratigraphy and succession of the rocks of the Sierra Nevada of California. *Bull. Geol. Soc. Am.*, vol. 3, 1891, pp. 413–444.

Notes upon the surface geology of Rio Grande do Sul, Brazil. Edited by J. C. Branner. *Amer. Geologist*, vol. 29, February, 1902, pp. 126–127.

Unpublished: The geology of the Sierra Nevada as exhibited in a detailed section through Plumas county, California. Assisted by William Watson. The map accompanying this paper covers 160 square miles, on a scale of 1 to 12,000, and other maps cover an area of 800 square miles, on a mile to the inch scale.

Following the memoirs the Committee on Entertainment, through Mr George H. Eldridge, chairman, made announcements concerning the dinner and other events.

The President declared the scientific program in order, and the Secretary stated that the Council had passed the following resolution:

"*Resolved*, That the Council of the Geological Society of America invites the members of Section E, American Association for the Advancement of Science, to present their papers now on the Section E program before the Geological Society: *Provided*, That such papers as are accepted for reading by the Council of the Geological Society be regarded as Geological Society papers."

The first paper presented was the following:

THE FIRST EPARCHEAN FORMATION

BY H. M. AMI

The paper was discussed by C. R. Van Hise, Bailey Willis, A. R. Lane, A. W. Grabau, the author, and the President. A short abstract is published in Science, volume xvii, page 290.

The second paper presented was

BASAL CONGLOMERATE IN LEHIGH AND NORTHAMPTON COUNTIES, PENNSYLVANIA

BY FREDERICK B. PECK

Contents

Scope and Purpose of the Paper

In the present paper no attempt is made to cover the entire area represented by Lehigh and Northampton counties even, or to treat the subject at all exhaustively, but rather to describe briefly certain phases of this basal series as it occurs near Easton, on the Delaware river, in Northampton county, and at a few other localities southwest of Easton, in Lehigh, including one locality just over the line in Berks county.

Application of the Term "Basal Conglomerate"

The term "basal conglomerate" as here used refers to that lowest member or series of beds belonging to the Cambrian which lies unconformably on the pre-Cambrian gneisses, but is conformable with the overlying lower Cambrian dolomites. It presents a variety of phases, at times assuming the character of a rather coarse conglomerate, an arkose, a dense fine grained bluish or grayish quartzite, an impure argillaceous quartzite, or a dense ferruginous, somewhat jaspery, quartzite.

Previous Descriptions of the Beds Elsewhere

This series has already been fully described by Mr Walcott * as it occurs farther to the southwest in York county. It has also been described by Wolf and Brooks † in Essex county, New Jersey, as the "Hardistonville quartzite," and by Kummel and Weller ‡ from the same locality as the "Hardiston quartzite," the latter gentleman preferring the shorter and more convenient local name of the township in which, rather than of the town near which, typical outcrops occur.

General Description

The band of pre-Cambrian rocks which extends across the northern portion of New Jersey as a series of parallel ridges, with intervening valleys of Cambrian dolomites and dolomitic limestones, crosses the eastern border of the state of Penn-

* Bull. U. S. Geol. Survey, no. 134, 1897.

† U. S. Geol. Survey, Eighteenth Annual Report of the Director, part ii, p. 442 et seq.

‡ Bull. Geol. Soc. Am., vol. 12, p. 149 et seq.

sylvania between Easton on the north and Kintnersville on the south, having in the main the same northeasterly and southwesterly trend.

More detailed Description of special Localities

The northernmost of these ridges, Chestnut hill, lies north and west of Easton. It consists largely of dense hornblende and augite gneisses, which dip at an angle of from 40 to 60 degrees to the southeast. The ridge diminishes in altitude toward the southwest and at a distance of 4½ miles from Easton disappears under the Cambrian dolomites. Along the northern border of this ridge runs a typical break thrust fault by which the pre-Cambrian gneisses are forced up over the Cambrian dolomites, as a result of which the lowest member of the Cambrian (the conglomerate) is wanting. Movement of a somewhat different character has taken place along the southern margin of the ridge, as a result of which the basal member is here again wanting, except at two points—one on the Delaware river, where, faulted in between a granite wall on the south and a gneissic wall on the north, is a slaty mass of more or less ferruginous quartzite, showing under the microscope well rounded grains of quartz having a cementing material of quartz (?) tinged with a brownish or reddish dust of iron ore, which in the neighborhood of the walls has been reduced by shearing to magnetite grains. The other occurrence lies at the extreme southwestern end of Chestnut hill and constitutes a small, poorly defined area of a similar kind of rock. These two occurrences may be interpreted as showing the former extension of the lowest Cambrian over the northeasternmost area of pre-Cambrian rocks, and as showing that its failure to appear continuously is due to faulting and not to a lack of deposition.

Two miles south of Easton lies the next most northerly ridge of pre-Cambrian rocks, which continues with a single interruption at Shimersville, in a southwesterly direction across the southern portion of Northampton and Lehigh counties into Berks. Along the northern margin of this area from the Delaware river to Bethlehem, with one exception (this on the Delaware river), no outcrops of the basal conglomerate or quartzite occur; but from Bethlehem toward the southwest it increases in importance, and it is from this region that I desire more particularly to select occurrences for special consideration. At no one place could all of the different phases of the basal series be found in undisturbed stratigraphic sequence; neither could their total nor their individual thickness in any case be accurately measured; yet, in considering the dip of the beds and the relative distance of a given outcrop from the underlying pre-Cambrian gneisses, some conclusion could be arrived at, both as to the relative position of the beds and to their total thickness.

The following is a description of some of the more striking characteristics or phases of the basal series as exhibited at a few of the more typical localities, and, so far as could be determined, they are described in the order of their sequence, beginning with the lowest.

One mile northwest of Vera Cruz, in Lehigh county, is to be found a coarse pebbly conglomerate, consisting of rounded, sometimes also more or less angular, pebbles and fragments of quartz and feldspar, the pebbles occasionally having a diameter of 2 or 3 inches, the same imbedded in matrix of finer materials consisting also of quartz and feldspar. This seems to be quite uniformly the character of the lowest member of the series, and in a number of instances it was found to

pass by almost imperceptible gradations over into the underlying granitoid gneiss in such a manner as to suggest the decidedly rapid submergence of a deeply weathered Cambrian land mass, with a correspondingly rapid advance of the sea over the same, affording insufficient time for the thorough sorting of the loose materials already at hand or the bringing in of any considerable amount of sediment from a distance. The entire basal series, here representing as it does distinctly littoral or at least shallow water deposits, has a total thickness of only a few hundred feet at the most, and the conditions under which it was deposited must have rapidly changed to those necessary for the deposition of the offshore and distinctly deep water sediments represented by 2,000 or 3,000 feet of dolomites and dolomitic limestones which immediately succeed it.

At Macungie, 2 miles farther west, we find a rather fine grained bluish or grayish quartzite, which weathers superficially to a brownish color, lying apparently above the horizon of the conglomerate just described. The beds approach a horizontal position, dipping at an angle of about 15 degrees to the north. It gives evidence microscopically of a considerable amount of squeezing and stretching, as shown in a well defined cleavage and occasionally in a sort of stringy or fibrous appearance. Under the microscope the grains of quartz are seen to be much broken and crushed, or it may be drawn out so as to have one much elongated diameter. The wavy or undulating extinction of the larger plates is very pronounced, and a cataclastic structure is sometimes beautifully developed.

With the quartz occurs quite uniformly at least a small amount of feldspar. This constituent frequently becomes of primary importance, in which cases the rock assumes the character of an arkose. This phase of the basal conglomerate is often the prominent one. The feldspar is usually kaolinized, and in weathered specimens appears as white, floury points and blotches scattered through the rock. It is sometimes fresh enough, however, to be determined under the microscope as orthoclase or microcline. As accessory minerals might be mentioned an occasional flake of biotite or muscovite, with here and there a fragment of rutile or a grain of zircon or of titanite. The cementing material, which is very meager, is silicious.

Two miles farther west, at Alburtis, the same beds furnish even better exposures than at Macungie. Here, as the result of a slightly overturned fold, beds dip at an angle of from 70 degrees to 85 degrees to the south and toward the gneiss. They can be traced to the west almost continuously by good outcrops across the Berks county line to a point 1 mile south of Shamrock. Here, interstratified with a rather coarsely granular bluish or grayish quartzite, are a few feet of impure, very fine grained, argillaceous quartzite, filled with the casts of worm borings (scolithus). This is the only fossil thus far discovered at any of the above named localities in the basal series. It is hoped, however, that a continued search will discover some distinctively Lower Cambrian species.

This is the most favorable locality within the area described for obtaining an estimate of the thickness of the series. Here, measuring across the upturned edges of the beds, we have an exposure about 50 feet thick; and they are probably much thicker, for in averaging the distance between this outcrop of quartzite and the gneiss on the south side and the distance of the quartzite from the dolomite on the north side we should have to assume a thickness of 300 feet or possibly several hundred feet.

That member of the basal quartzite which in this region lies at the summit of

the series and next to the dolomite is a dense, highly ferruginous, almost jaspery quartzite. It is frequently brecciated and recemented by an abundant infiltration of quartz, which may be either of a chalcedonic nature or distinctly crystalline. The quartz frequently covers the broken surfaces and lines the walls of cavities in its drusy form. This phase of the quartzite is well developed at Emaus. The decomposed highly ferruginous quartzite of this horizon here, as well as at numerous other localities in Lehigh and Northampton counties, carries percentages of iron high enough to constitute a low grade ore, and it was formerly one of the important iron bearing horizons of the region. No equivalent of the "York shales"* could be found lying between the quartzite and the overlying dolomites.

Summary

The basal conglomerate or quartzite series, as it occurs along the northern margin of the pre-Cambrian area in Northampton and Lehigh counties, presents in the main the same lithological characters as its equivalent to the southwest in York county, except that the uppermost member in the former region is wanting in the latter; also when compared with the same beds to the northwest in northern New Jersey there is a striking similarity. The failure of these beds to appear in the intervening region along the Delaware river in Northampton county, particularly in the immediate vicinity of Easton, is due to thrust faulting, by which the pre-Cambrian gneisses have been forced up over the Cambrian dolomites.

The basal quartzite series in Lehigh county begins at the base with a few feet of coarse conglomerate, which fades over into the underlying pre-Cambrian gneisses with no sharp line of demarcation. It is followed by a typical arkose, which at times changes to dense bluish or grayish quartzite, having interstratified with it a few feet of impure, fine grained quartzite containing scolithus. The uppermost member of the series is a very fine grained, almost jaspery, frequently highly ferruginous quartzite, which here constitutes one of the important iron bearing horizons. The series is the northeastern extension of beds which, in York county, have been called by Walcott the Hallam quartzite, and is the equivalent of the Hardiston quartzite of Kummel and Weller in northern New Jersey.

Remarks on the subject of the paper were made by Bailey Willis and the author.

First Vice-President S. F. Emmons was called to the chair and the third paper was read, as follows:

SANDSTONES OF THE OZARK REGION IN MISSOURI

BY C. F. MARBUT

An abstract of this paper was published in Science, volume xvii, page 291.

Remarks were made by Professor A. H. Perdue, a visitor.

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* Bull. U. S. Geol. Soc., no. 134, p. 14.

The fourth and last paper of the morning's session was

*DEVONIAN AND CARBONIFEROUS ROCKS OF SOUTHWESTERN NEW YORK**

BY L. C. GLENN

[*Abstract*]

Contents

Introduction

During the summer of 1900 the detailed geological mapping of the Olean and Salamanca quadrangles in southwestern New York was undertaken by the United States Geological Survey in cooperation with the state of New York, and the writer was placed in charge of the work. The work was continued and finished the next summer. Mr Myron L. Fuller assisted largely in the work on the Salamanca quadrangle the latter season, and during both seasons Mr Charles Butts made extensive paleontological collections from the two quadrangles and the adjacent region. Reconnaissance work was pushed southward to Bingham, Pennsylvania, and westward across McKean and Warren counties to near Corry, Pennsylvania.

Purpose of Paper

It is the main purpose of this paper to describe briefly the stratigraphic succession found in the Olean-Salamanca region, to state the paleontological conclusions so far reached as to the age of the formations, and the results of the efforts

*The full paper is published in the Report of the New York State Paleontologist for 1902, pp. 967–989.

made to trace these formations southward and westward into McKean and Warren counties, Pennsylvania.

Age of Rocks and Problems involved

The Paleozoic rocks exposed in the quadrangle extend from about the middle of the Chemung up into the Carboniferous. They consequently include the Catskill or its equivalent in the Upper Devonian and the boundary or transition between the Devonian and the Carboniferous. To the eastward in both New York and Pennsylvania the distribution of the Chemung, the Catskill, aud the Carboniferous rocks and their relationship to each other have received much study. To the southward in Pennsylvania the Carboniferous rocks have been studied and the Lower Carboniferous traced northward toward this region. To the west in Ohio the Carboniferous and Waverly have been studied and traced eastward for some distance into northwestern Pennsylvania. The Olean-Salamanca region, however, has been an unknown meeting ground into which, when attempts were made to trace beds that were distinct to the east, the south, or the west, the tracings became indistinct and the correlations uncertain.

Topography

Topographically the region is a maturely dissected one. The hills rise with steep slopes to an elevation of 500 to 1,000 feet above the main stream levels. The northern portion of the two quadrangles is glaciated and exposures of rock in place are infrequent. Much of the southern portion and of the reconnaissance area in Pennsylvania is wild and wooded, so that exposures are concealed and the work of the geologist is made difficult and slow.

Structure

The dominant structure is that of flat-lying beds dipping gently a little west of south at about 30 feet per mile. Here and there the dip is locally increased or decreased, and in the Olean and eastern Salamanca area, just south of the Alleghany river, it is for a short distance reversed. Some minor folding occurs in the Olean conglomerate on the ridge between Flatiron rock and Knapps creek. This folding is entirely taken up in the 1,800 feet of shales that intervene between the Olean conglomerate and the Bradford oil sand, which is penetrated by many wells at this depth, and shows no sign of folding. In the Salamanca region some low rolls or folds with northeast-southwest axes were noted by Mr Fuller.

Formations

Chemung shales and Cuba sandstone lentil

The oldest rocks in the region are those near stream level in the northeastern part of the Olean quadrangle. They are typical Chemung shales and extend upward some 700 to 750 feet. Of these the very lowest beds consist of 30 or 40 feet of fine olive green, argillaceous shales seen best exposed near Cuba.

Immediately above these shales there is a sandstone 10 to 15 feet thick, most prominently exposed in and north of Cuba in a number of quarry openings. It is a medium to coarse grained, somewhat arkosic sandstone, usually of a light cream

color and smelling strongly of petroleum on freshly fractured surfaces. Some of its layers are separated by thin shale films. Fossils occur rather abundantly in certain layers, and in the coarser parts an occasional small quartz pebble is found. The region in which it occurs above waterlevel is glaciated, and almost all cf its outcrops are concealed by till. It extends from North Cuba and Ischua, however, down Oil and Ischua creeks to near their junction where its dip carries it beneath floodplain level. A solitary exposure is found in a railway cut north of Great valley, on the Salamanca quadrangle.

From its exposure in quarries in and around Cuba this sandstone is known as the Cuba sandstone. It is regarded as a lentil in the Chemung formation.

Above the Cuba sandstone lentil, the Chemung is composed of green and brownish argillaceous and sandy shales, interbedded here and there with thin shaly sandstones. With the probable exception of certain dark purplish shales to be described presently, the individual beds of neither the shales nor the shaly sandstones usually retain their thickness or individuality or possess any lithological character that would enable any one of them to be traced and identified for any distance. The nearest approach to persistency in these variable beds is found in a sandy zone about 200 feet above the Cuba sandstone. A number of quarries have been opened in the past on some argillaceous sandstone at this horizon; but even this sandy zone, persistent as it is as a whole, well illustrates the variability in detail of these Chemung strata, for often in one quarry face there is visible a complete change along the bedding plane from one lithological phase to another, so that as a whole these Chemung shales and argillaceous sandstones are only regular in their irregularity and intergradation.

The one exception as regards the rapid variability of these shales is found in certain dark purple or chocolate colored shales about 325 to 350 feet below the top of the Chemung. They seem to be widely persistent and are found in many well borings to the south. Their top occurs in the Dennis well at Bradford, Pennsylvania, at a depth of 712 feet.

At a number of horizons the shales become locally calcareous and a few inches of them may pass into a very impure limestone that where exposed on the surface has usually been leached out into a honey-combed mass of brachiopod casts and molds. Ripple markings are common at various horizons, and in a few places what may possibly be obscure mud cracks are found.

CATTARAUGUS

Wolf Creek conglomerate lentil.—A marked change in the conditions of sedimentation caused the deposition of a conglomerate that is most prominently developed on Wolf creek and is known as the Wolf Creek conglomerate. Its pebbles are predominantly flat or discoid, and hence it is also often called the "flat-pebble" conglomerate in contradistinction to the Olean or "round-pebble" conglomerate occurring higher in the series. The pebbles are mostly of vein quartz, though a few are of red jasper. The mass of the rock is, as a rule, a coarse, loosely cemented, cross-bedded sand sometimes bleached white, but usually stained yellow or brown by iron. One of the most prominent characteristics of this conglomerate is its rapid variation in thickness. Nowhere more than about 20 feet thick, it often in a few hundred yards thins down to a few inches in thickness. Notwithstanding ts rapid variation in thickness it was found to be a remarkably persistent stratum

over the Olean and the eastern part of the Salamanca sheet and was the key rock for determining the stratigraphy of much of this region. It marks the first prominent change in sedimentary conditions in the region and is regarded as a lentil marking the base of, and belonging to, the Cattaraugus formation.

Shales and sandstones.—The Wolf Creek conglomerate was succeeded by bright red shales interbedded with green or bluish shales and fine grained, greenish gray, thin bedded, micaceous sandstones that together extend upward through an average interval of 300 to 350 feet. This portion of the stratigraphic column, in which bright red shales occur along with the Wolf Creek conglomerate lentil, is regarded as a formation, and to it the name Cattaraugus is given. Two other conglomerate lentils, the Salamanca and the Kilbuck, occur in it.

The bright red argillaceous shales of the Cattaraugus are entirely different from the dark brick red or purplish shales of the Chemung. No bright red shales occur in this region below Wolf creek, but they soon appear above it. They are usually fine grained and argillaceous, though in places they become sandy and may locally pass, especially southeastward, into thin red argillaceous sandstone. It is not certain that the individual beds of red shale are persistent or hold their thickness for more than short distances, but it is certain that westward in the Salamanca region and southwestward in Warren county, Pennsylvania, the beds of red shale tend to disappear. Their disappearance appears to be due to their grading over westward and southwestward into deposits of other than red color. The stratigraphic equivalents of the red shales are, as a rule, present to the westward, but their color has changed to olive green, blue, or drab. There are, however, evidences of erosion at this horizon, as will be seen later, but this erosion will not account for the disappearance of the reds.

The lighter colored shales interbedded with the red ones vary from fine blue mud shales to light or dark green sandy ones. Along with the shales are greenish gray, medium to fine grained, soft, arkosic sandstones, often thin or cross-bedded, and with their parting planes flecked with mica particles. The individual beds of sandstone do not seem, as a rule, to be persistent, except for short distances.

Fossils.—After the deposition of the Wolf Creek conglomerate, which contains in its upper portion especially a marine fauna, fossils rapidly disappear, and the red and green shales and the fine micaceous sandstones generally yield but few or, for considerable intervals, no forms. Conditions as a whole were evidently unfavorable to animal life while these beds were being deposited. The Salamanca and Kilbuck conglomerate lentils are, however, fossiliferous.

Salamanca conglomerate lentil.—The Salamanca lentil occurs at about the middle of the Cattaraugus formation. It thins out and disappears to the eastward. It occurs in the southwestern part of the Olean area as a hard gray sandstone 10 to 15 feet thick, which becomes coarser and thicker westward and passes into a massive conglomerate on the Salamanca quadrangle. The sandstone phase is well exposed in a number of small quarries on mount Herman just south of Olean, where it is locally known as the Mount Herman sandstone.

Its massive conglomeratic character is best developed in the Salamanca region, and may be well seen up Limestone and Irish brooks, along Red House creek, at Salamanca "rock city," and at numerous other places.

In thickness, coarseness, and massiveness it is also variable, though not as markedly or abruptly so as the Wolf Creek. In its more massive phase it is often strongly cross-bedded, and in places is separated into two benches, with a shale

parting between. The pebbles are mostly of vein quartz, and the great majority of them are distinctly flattened like those of the Wolf Creek, and, like the latter also, they include an occasional one of red jasper. The maximum thickness in the Olean-Salamanca region is rarely over 30 feet, and probably never exceeds 40.

Much confusion and uncertainty has arisen in the Salamanca region as to the number of conglomerates present beneath what has generally been called the Sub-Olean. This is especially true of that region bordering the valley of the Tunangwant or Tuna. Various correlations, some of which, however, were recognized as provisional, have been made for the same outcrops, and different outcrops of the same conglomerate have often been regarded as belonging to different horizons.

The names Salamanca, Panama, Pope Hollow, Wrightsville, and even Sub-Olean (?) have all been applied in this region to the same conglomerate, some of them being regarded by some as synonymous, but the belief being prevalent that two or three conglomerates are present in the Tuna section.

The lower conglomerates found by Randall * northeast of Carrollton and up Baillett brook, and perhaps in a few other neighboring localities, is the Wolf Creek, here locally much thickened as compared to its usual development in this region. His higher conglomerate is the Salamanca.

The Salamanca, the Panama, the Pope's Hollow, and the Tuna are the same conglomerate, and Lesley's † supposed third or Sub-Olean (?) conglomerate at Ireland, near the head of Irish brook, is also an excellent outcrop of the Salamanca. The confusion has mainly resulted from assuming a regular dip for the Salamanca and then concluding that a conglomerate found too high or too low at a given locality for the calculated position of the Salamanca at that place belonged to a different horizon. Dips, however, are not regular in this region, and such dip calculations are misleading.

Kilbuck conglomerate lentil.—On the Salamanca sheet there is found locally developed in the Cattaraugus formation a third conglomerate lentil lying 50 to 70 feet above the Salamanca conglomerate and called by Mr Fuller the Kilbuck. It has much the same flat-pebble character as the underlying Salamanca. It is not over 10 to 15 feet thick as a maximum, but in places is quite massive and weathers into large flat blocks that, where topographic conditions favor, form a pavement over considerable areas. It is best developed northeast and east of Kilbuck. Though its areal extent is not great, it has possibly added to the difficulties of making correct correlations in this region.

Probable unconformity.—The top of the Cattaraugus formation is difficult to determine with exactness in most places, since its upper portion consists of soft shales and it is succeeded by other soft shales. Exposures are in consequence poor, except along roadways or pipe lines. Numerous measures, however, that are deemed reliable have been obtained of the thickness of that part of the formation which lies above the top of the Salamanca conglomerate lentil. A comparison of these figures shows that this thickness frequently varies irregularly and very materially within short distances. It is not thought probable that mere local variations in the thickness of the strata of the Cattaraugus could be rapid enough and great enough to account for this irregular variation. It seems more probable that the

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* F. A. Randall: Preliminary Report on Geology of Cattaraugus and Chautauqua Counties, in Report of State Geologist of New York for 1892–1893, pp. 713–721.

† J. P. Lesley: Sum. Fin. Rept. Pa. Geol. Survey, vol. ii, pp. 1531–1532.

upper surface of the Cattaraugus is irregular because of erosion, and that there is an unconformity between the Cattaraugus and the succeeding Oswayo.

OSWAYO

Composition.—The close of the Cattaraugus was marked by the cessation of the deposition of red shales in this region. After what is believed to have been an erosion interval it was followed by the deposition of olive green to rusty colored sandy shales, with here and there thin sandstone layers with limonitic seams or incrustations. These greenish, limonitic shales constitute the Oswayo formation. Its thickness varies from 160 to 250 feet, the average being near the latter number. Conditions now became more favorable to the existence of life, and, in contrast to the usual barrenness of the red shales below, the Oswayo contains in many places a fairly good representation of marine invertebrates, prominent among which is *Camarotœchia allegania*, which serves as an excellent horizon marker.

Limestone layer.—A few feet above the base of the Oswayo shale is found in a number of places in New York what seems to be a persistent layer of very impure limestone. It is only 1 or 2 feet thick and the entire stratum is composed of innumerable fragments of badly broken brachiopod and other marine shells.

Near the top of the Oswayo, on the Olean quadrangle, the shales become sandier, and at Olean Rock City there are some traces of thin grits about 40 feet below the base of the Olean. Nowhere on this quadrangle, however, have such gritty beds been found exposed in place, and at several points good exposures of this part of the section are to be seen—as, for instance, on the road from Fourmile down into Fourmile Creek valley.

KNAPP FORMATION

On the Salamanca quadrangle there are found beneath the Olean conglomerate two thin conglomerates interbedded with shales that are lithologically very similar to the underlying Oswayo shales. These are doubtless, in part at least, the equivalents of the grits and shales just beneath the Olean at Rock City and which are included in the Oswayo there, but which evidently thicken and coarsen westward until they are capable of differentiation as the Knapp formation. These beds are not usually well developed on the Salamanca quadrangle, and have been found in only a few areas along the southern edge. Southwestward in Pennsylvania a more prominent conglomerate, known as the Sub-Olean, is situated in a similar stratigraphic position beneath the Olean, from which it is separated by from 25 to 30 feet of shales. It is known over a large area and extends, according to the Pennsylvania geologists, westward into Ohio, where it is known as the Shenango conglomerate. It, with the associated Shenango shales, is probably the equivalent of this Knapp formation.

The coarser part of this formation is usually a loosely cemented conglomerate with small, well smoothed quartz pebbles of flattened discoidal shape that only in places becomes massive. It is frequently highly limonitic, and in most places where examined was fossiliferous. The fossils consist of marine invertebrates and plant stems of various kinds. The shales are sandy and olive green or rusty brown and in several places contain marine invertebrates.

In places these beds have been cut out by erosion before the deposition of the Olean conglomerate—as, for instance, on the ridge north of the head of Irish brook, where Olean caps the hill—but with no sign of an underlying conglomerate

beneath. The same thing is true at Millers cliff, in Warren county, Pennsylvania, where the Olean occurs, but beneath it the Sub-Olean is wanting. From differences of level in the base of the Olean as exposed in outcrops often but short distances apart, the floor upon which the Olean was deposited must have been a very irregular one. This unconformity separating the Pennsylvanian and the Mississippian series is believed from the work of Mr David White and others to be of widespread occurrence southward in Pennsylvania.

POTTSVILLE—OLEAN CONGLOMERATE

Next comes a massive round-pebbled conglomerate, widely known as the Olean conglomerate. In texture the Olean often varies quite rapidly, both horizontally and vertically. In some places or in some beds it is scarcely more than a coarse sandstone with a sparing development of pebbles, while at other places or in other layers at the same place it is almost entirely composed of rounded quartz pebbles. It is often strongly cross-bedded. The pebbles are well rounded and, in contrast to the flattened or discoidal pebbles of all of the underlying conglomerates in the region, are predominantly ovoid in shape. Most of the pebbles are of vein quartz; a few are of a hard, dark gray slate; none are of red jasper.

They are embedded in an arkosic matrix, in portions of which there is considerable iron, which has formed thin, limonitic streaks or crusts through the rock and resists disintegration better than the arkosic cement does. Pebbles of vein quartz on firmly cemented surfaces are sometimes found much etched or corroded.

Disintegration of the Olean is, as a rule, rapid, and talus slopes conceal the base. Numerous well borings, however, on the Olean quadrangle give an accurate measure of its thickness there, which is usually between 60 and 70 feet, though in one well it is 90 feet. It occurs on the highest hilltops in the southern part of the two quadrangles in a number of small detached areas, and is well known southward in McKean county and westward in Warren county in Pennsylvania.

Above the Olean conglomerate at Rock City are found a few feet of thin, sandy, furruginous shales, in which some years ago a thin coal bloom was exposed in grading a road. It also belongs to the Pottsville.

AGE OF THE FORMATIONS

The extensive collection of fossils made by Mr Charles Butts were studied by him at Albany under Dr J. M. Clarke's supervision. Professor H. S. Williams has also studied similar collections made by himself and his assistants in this region, and the paleontological facts stated below concerning faunal affinities are those ascertained as a result of the investigations of Doctor Clarke, Doctor Williams, and Mr Butts.

The conclusions which the writer has drawn from these paleontological facts he alone is to be held responsible for.

The shales extending from the lowest exposures up to the base of the Wolf Creek conglomerate contain an abundant Chemung fauna, and are considered to be of Chemung age. The first Carboniferous life forms appear with the incoming of the Wolf Creek conglomerate, and from this point up to practically the base of the Olean conglomerate at Olean Rock City, where the last Devonian forms disappear, there is a mingling of Devonian and Carboniferous forms, the Devonian slowly decreasing, the Carboniferous slowly increasing. The essential fact, so far as the life of these Cattaraugus and Oswayo formations is concerned, is that there is an over lapping of Devonian and Carboniferous faunas. With this essential fact recognized,

the position at which the boundary line between the Devonian and the Carboniferous shall be drawn becomes, in some measure at least, a matter of convention.

It might appear best for some reasons to draw this line at the base of the Wolf Creek, where Carboniferous forms first appear, and consider both the Cattaraugus red beds and the Oswayo and Knapp formations as Lower Carboniferous.

Because of the thickness of these red beds and their reasonably certain stratigraphic equivalence with the red beds of the Catskill to the east, and because of the unconformity believed to exist between the Cattaraugus and the Oswayo, the writer prefers to draw a provisional boundary between the Devonian and the Carboniferous at this point.

All of the facts bearing on this difficult Devono-Carboniferous boundary problem will not be at hand until paleontologic researches from both the Devonian and Carboniferous starting points have been finished and detailed stratigraphic work has been carried eastward, southward, and westward to connect with better known and more clearly differentiated areas in these directions. Hence this boundary is to be recognized and accepted as distinctly provisional only, and is subject to such change as later investigations of the stratigraphy and paleontology of the adjacent regions may warrant.

The Olean has been agreed on as Carboniferous, but there has been considerable difference of opinion as to just what portion of the Carboniferous it represents, although the weight of opinion has been in favor of its age being Pottsville. Very recent field studies by Messrs M. R. Campbell * and David White are regarded by them as definitely establishing its Pottsville age. It is still doubtful, however, as to what part of the Pottsville it represents. It may be the equivalent of either the Connoquenessing or of the Sharon, with the probabilities somewhat in favor of the former. If it be equivalent to the Sharon, the few feet of overlying shale represent the Sharon shale and the thin coal bloom the upper Marshburg coal. If it be the Connoquenessing, the overlying shale and coal belong to the Alton or Merrcer Coal group. Detailed work to the south and west will be necessary to settle this point.

Results of a Reconnaissance into Pennsylvania

WOLF CREEK CONGLOMERATE

A reconnaissance was made southward into McKean county, Pennsylvania, and then westward on both sides of the state line nearly to the western edge of Warren county, Pennsylvania.

South of Ceres the Wolf Creek conglomerate is well developed along Kings run, being in places fully 20 feet thick, but weathering into pieces a few inches to a few feet thick. It dips under stream level a short distance north of Glenn post-office. West of this point on the road to Eldred it appears at the upper fork of Newel creek and is again seen on the road just south of the upper fork of Barden brook, whence it may be traced to Eldred, where it outcrops 180 feet above railway level. It is represented in the Dennis well at Bradford by part or all of the 35 feet of sandstone with base at 1,680 feet above tide. West of Bradford it is not satisfactorily identified. It probably loses its character even as a sandstone and soon entirely disappears westward.

SALAMANCA CONGLOMERATE

No traces of the Salamanca conglomerate were found south of Ceres or near Eldred. In the Dennis well at Bradford it is represented by the 23 feet of sand-

* Personal letters from Mr M. R. Campbell, April 18 and 27, 1903.

stone with "a few pebbles," having its base at 1,817 feet above tide. West of Bradford it is found up Marilla creek, and west of Marilla summit it occurs on Corydon creek. It is again found west of the Allegheny river, both in Pennsylvania and south of Steamburg in New York, and from its elevation, its position in the section, and its lithological character, as well as by its tracing westward, I conclude that it is the same as the Pope Hollow conglomerate, which may be traced south from Pope Hollow past Fentonville and Russelburg by exposures at intervals along either valley wall of the Conewango to the Asylum quarry at north Warren. It may be traced westward up Rhinds run or Jacksons run by numerous exposures to a point on Jacksons run about 2 miles east of Chandlers valley. All exposures from here to Sugar Grove are covered with glacial till, but it is quarried a short distance west of Sugar Grove, is found just above the mouth of the Lottsville well No. 1,* and may be traced at intervals along the Little Brokenstraw valley northward past Grant station until there can be no doubt of its being the Panama conglomerate. Tracing it southward from Lottsville it passes about 225 feet beneath the Wrightsville conglomerate at Wrightsville and is doubtless the pebbly sandstone found "about 100 feet from the surface" in the Rocky Hollow well † about a mile northeast of Wrightsville. It seems probable that farther south this Salamanca-Pope Hollow-Panama conglomerate may be the same as the third Venango oil sand if that sand has a northward representative at all. In this northwestern part of Warren county the shales and thin, soft, micaceous sandstones that extend for a couple of hundred feet above the Panama conglomerate weather into a steep but smooth slope that is highly characteristic and bears when cleared, as it usually is, a characteristic vegetation. These shales, with their characteristic topography and vegetation, often aided in tracing the underlying Panama where it was not exposed or had even dipped somewhat beneath drainage level.

WRIGHTSVILLE CONGLOMERATE

The Wrightsville conglomerate can not be identified with the Panama, but lies about 225 feet higher in the section. It seems reasonable to suppose that it is the equivalent of the Venango first sand, as is believed by Lesley, though no attempt was made by the writer to trace it to a connection with that sand.‡

OLEAN AND SUBOLEAN CONGLOMERATES

The Olean conglomerate was found on Mount Raub near Bradford, and occurs on the hills south of Bradford, decreasing gradually in elevation until it is last exposed in the Buffalo, Rochester, and Pittsburg railway cut just north of Bingham station as an irregularly bedded sandstone. Here it dips under the plateau surface. No examination was made of the region south of the divide where it doubtless reappears. The Olean conglomerate and the Shenango conglomerate and shale are traceable westward across Warren county. All occur on Quaker hill and at Pikes rocks and elsewhere. The Olean occurs at Millers rocks, but the Shenango seems to have been cut out there just as its equivalent, the Knapp formation, has been near the head of Irish brook and elsewhere, as previously noted.

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*See J. F. Carll: Second Geol. Survey of Pennsylvania, Report I 4, pp. 199, 232.

† J. F. Carll: Second Geol. Survey of Pennsylvania, Report I 4, p. 236.

‡ For the opinions of the geologists of the Second Pennsylvania Survey on the correlations of the various members mentioned in the preceding paragraphs see I. C. White, Report Q 4, pp. 99–116; J. F. Carll, Report 3, pp. 57–80, and 4, pp. 195–208, and pp. 304–308 (F. A. Randall); J. P. Lesley, Summary Final Report, vol. 2, pp. 1493-1536.

LOCAL PEBBLE BEDS

During the reconnaissance locally developed pebbly beds, usually only a few inches in thickness, were found at several points. These thin pebbly beds occupy no definite horizon, but apparently may occur almost anywhere in the Cattaraugus or Oswayo formations. In no case was any one of them found to be persistent or to possess any stratigraphic importance. They were revealed usually by chance in some unusually good exposure in a railway cutting, by the roadside, or along a stream bank, and would ordinarily have entirely escaped observation. It is possible that at some point in the region such a pebbly bed may thicken into a locally prominent stratum and become a source of perplexity and possible error in tracing the stratigraphy if no nearby measure to a known horizon were obtainable as a check.

FUCOIDS

Fucoidal remains in the shape of vertical tubes piercing the sandstone or conglomerate layers of the Salamanca are especially characteristic of that horizon, and in its northeastern portion were often used as an aid in its identification, though in all cases of doubt reliance was placed in its invertebrate fauna. Southwestward, in Warren county, Pennsylvania, while vertical fucoidal remains are still often very prominent in the Salamanca, they also occur at other horizons, and hence if they may be used at all in that region as an aid in identification, it must be done only with a recognition of this fact in mind.

Remarks on Professor Glenn's paper were made by J. M. Clarke, H. S. Williams, T. C. Hopkins, David White, and the author.

At 12.45 p m the Society adjourned for the noon recess and convened at 2.10 o'clock, President Winchell in the chair. The first paper of the afternoon session was

STRATIGRAPHIC RELATIONS OF THE RED BEDS TO THE CARBONIFEROUS AND PERMIAN IN NORTHERN TEXAS

BY GEORGE I. ADAMS

This paper is printed as pages 191–200 of this volume.

The President asked Professor W. M. Davis to take the chair. The second paper was read as follows:

COMPARISON OF STRATIGRAPHY OF BIG HORN MOUNTAINS, BLACK HILLS, AND ROCKY MOUNTAIN FRONT RANGE

BY N. H. DARTON

A short abstract is printed in Science, volume xvii, page 292.

The third paper was the following:

AGE OF THE ATLANTOSAURUS BEDS

BY WILLIS T. LEE*

[*Abstract*]

The paper dealt with the extension of the Atlantosaurus shales from their type localities along the Rocky Mountain front southward into New Mexico and east-

*Introduced by W. B. Clark.

ward into Oklahoma. The shales contain fossils by which they can be correlated with the lower cretaceous of Texas.

The paper was discussed by W. B. Scott, S. W. Williston, N. H. Darton, and T. W. Stanton.

The fourth paper was

CRETACEOUS-EOCENE BOUNDARY IN THE ATLANTIC COASTAL PLAIN

BY W. B. CLARK

Remarks were made by Bailey Willis. A short abstract is printed in Science, volume xvii, page 293.

The fifth paper was

SHIFTING OF FAUNAS AS A PROBLEM OF STRATIGRAPHIC GEOLOGY

BY H. S. WILLIAMS

The subject of the paper was discussed by J. J. Stevenson. The paper is printed as pages 177–190 of this volume.

The sixth paper was

AMES KNOB, NORTH HAVEN, MAINE

BY BAILEY WILLIS

The paper was discussed by G. O. Smith, H. M. Ami, and G. C. Curtis, a visitor. It is published as pages 201–206 of this volume.

Professor H. S. Williams took the chair, and the seventh and last paper of the afternoon session was read, as follows:

GEOLOGY OF BECRAFT MOUNTAIN, NEW YORK.

BY AMADEUS W. GRABAU

[*Abstract*]

Becraft mountain, in Columbia county, New York, is an outlier of the Helderberg mountains. Its base is formed by the upturned and eroded rocks of the "Hudson" group, chiefly the Normans Kill shales. Unconformably on this rests the Manlius limestone (upper part), followed in turn by the members of the New York Devonian up to and including the Onondaga limestone. A detailed geological map had been prepared by the author for the New York State Survey, Department of Paleontology, and was exhibited by permission of the state paleontologist. The structure of the eastern and southern portions of the mountain, which is of the Appalachian type, was discussed. The excessive folding and faulting of this portion of the mountain was also illustrated.

The paper has since appeared in full in the report of the New York State Paleontologist for 1902.

Remarks were made by Bailey Willis, H. M. Ami, and the author.

Section of Petrography

During Tuesday afternoon, while the papers described above were being read in the general session, a number of petrographic papers were read in an adjacent room, Professor B. K. Emerson in the chair.

The first paper presented was one from the program of Section E, American Association for the Advancement of Science, presented by J. P. Iddings and H. S. Washington, entitled:

QUANTITATIVE CHEMICO-MINERALOGICAL CLASSIFICATION OF IGNEOUS ROCKS

BY WHITMAN CROSS, J. P. IDDINGS, L. V. PIRSSON, AND H. S. WASHINGTON

The matter of the paper is published in a book by the same authors, printed by the University of Chicago Press, entitled "Quantitative Classification of Igneous Rocks."

The second and third papers were read and discussed together.

CHEMICAL COMPOSITION OF IGNEOUS ROCKS EXPRESSED BY MEANS OF DIAGRAMS

BY J. P. IDDINGS

[*Abstract*]

The diagrams expressed the molecular proportions of the chief chemical components of igneous rocks; the range of their variation; the gradations of igneous rocks chemically between extremes; the grouping of them according to the system of quantitative chemico-mineralogical classification recently proposed by Cross, Iddings, Pirsson, and Washington. The paper closed with a correlation of igneous rocks classified on the quantitative basis with the same rocks classified on the qualitative basis.

QUANTITATIVE DISTRIBUTION OF ROCK MAGMAS

BY HENRY S. WASHINGTON

[*Abstract*]

The relative abundance of rock magmas belonging to the various divisions of the quantitative, chemico-mineralogical system of classification recently proposed, was discussed, with remarks on the special distribution of some of them. The advantages of the new system for the treatment of such problems were pointed out and compared as to certain respects with the old. A large collection of analyses of igneous rocks, on which the discussion was based, was briefly described.

The two papers were discussed by A. C. Lane, G. P. Merrill, W. H. Hobbs, Whitman Cross, J. F. Kemp, A. C. Gill, and the Chairman, B. K. Emerson.

The fourth and last paper read in the Petrographic Section was

NEPHELINE SYENITE AREA OF SAN JOSÉ, TAMAULIPAS, MEXICO

BY GEORGE I. FINLAY AND J. F. KEMP

[*Abstract*]

The San Carlos mountains, in the state of Tamaulipas, Mexico, are largely made up of nepheline syenite. This rock is exposed for ten miles along the range south of the town of San José. With it are associated syenite, dacite, and andesite in the form of a laccolith, and dikes of tinguaite, camptonite, and diabase. The general geology of the San José district is given, with a discussion of the field relations of the above rock types. They were described petrographically, and their mineralogical and chemical relalions treated in accordance with the scheme of classification outlined above.

Remarks were made by J. P. Iddings and H. S. Washington.

The paper will be found in full in the Annals of the New York Academy of Sciences for 1903.

Session of Tuesday Evening, December 30

The session was called to order at 8 o'clock p m in the banquet-room of the New Willard Hotel by First Vice-President S. F. Emmons.

The President of the Society, Newton H. Winchell, was introduced and delivered the presidential address, entitled

WAS MAN IN AMERICA IN THE GLACIAL PERIOD?

The address is printed as pages 133–152 of this volume.

Following the address a "Smoker" was given by the Geological Society of Washington to the Fellows of the Geological Society of America and other visiting geologists.

Session of Wednesday, December 31

The Society met at 9.45 a m, Vice-President S. F. Emmons in the chair.

The Council report was taken from the table and adopted without debate.

Professor W. H. Hobbs asked for information as to the delay in publication of volume 13 of the Bulletin. The Editor, Mr J. Stanley-Brown, explained that it was due to delay in obtaining proofs from authors, especially during the summer. After some discussion it was voted that the Publication Committee should have power to hold belated papers for the succeeding volume.

The proposed changes in the By-Laws submitted by the Council at the Rochester meeting were called up for action. After a brief discussion they were adopted, as follows: In chapter IV, section 1, add the following two sentences: "This ticket must be approved by a majority of the entire Council." "The nominee for President shall not be a member of the Council." In section 2 make the following three changes in verbiage: Change "forty days" to "nine months." Change "20 days" to "40 days." Change "15 days" to "25 days."

The Secretary read a telegram of greeting from the Cordilleran Section, then holding its annual meeting in San Francisco. The Society instructed the Secretary to return its cordial greeting.

Several announcements were made of details concerning the order of papers, etcetera, and that the rearranged set of photographs owned by the Society was displayed in an adjoining room.

The memoir of Alpheus Hyatt, deferred from Tuesday morning, was read by W. O. Crosby. (See page 504.)

The first paper of the scientific program was one received from the list of Section E, American Association for the Advancement of Science, entitled

ECONOMIC GEOLOGY OF MICHIGAN

BY ALFRED C. LANE

The paper was discussed by J. F. Kemp, W. M. Davis, and W. N. Rice. A short abstract is printed in Science, volume xvii, page 218.

The second paper was

PALEOZOIC CORAL REEFS

BY A. W. GRABAU

The subject was discussed by A. C. Lane, H. S. Williams, H. L. Fairchild, and T. C. Chamberlin. The paper is printed as pages 337–352 of this volume.

The third paper was

PRIMITIVE CHARACTERS OF THE TRIASSIC ICHTHYOSAURS

BY JOHN C. MERRIAM

[*Abstract*]

Extensive collections of ichthyosaurian material which have recently been made in the Upper Triassic of California have brought to light a considerable number of species and genera heretofore unknown. Some of these forms exhibit peculiar specializations not found in other representatives of the order. There are, however, a number of primitive characters which are quite strongly marked. These characters are of considerable interest, as they assist somewhat in the attempt to determine the character of the primitive ichthyosaurian.

Leaving out of account such characters as are doubtfully primitive, the following are some of the structures indicating a less marked degree of specialization than is found in the purely aquatic, fish-like ichthyosaurs of the Jurassic:

1. Vertebral center either perforated or deeply biconcave.
2. Either a larger number of cervical intercentra than in the Jurassic forms or the atlas and axis simpler.
3. Zygapophysial facets of cervical and dorsal vertebræ large, separate, and not usually in the same plane.
4. Neural spines in cervical and dorsal regions, thick, sometimes circular in cross-section.
5. Scapula, pubis, and ischium expanded distally, elements of pelvic arch generally robust.
6. Hind limbs sometimes as large or larger than the anterior.
7. Epipodial and phalangeal elements of anterior and posterior limbs generally elongated and showing a median constriction.

The fourth paper was received from the Section E list, entitled

PALEONTOLOGICAL WORK IN NEW YORK

BY JOHN M. CLARKE

[*Abstract*]

(*a*) The Guelph reefs and their faunas. Recent investigations have shown an excellent development of the Guelph fauna at at least two stages in the upper Siluric dolomites of New York, and an analysis of the character of the species and the nature of the inclosing rock indicates that the fauna flourished on and about coral reefs in a shrinking sea.

(*b*) The faunistic provinces of Portage time. In addition to the provinces already established during this stage in New York, namely, the eastern or Oneonta, the central or Ithaca, the third or Naples (= true Portage), the last proves divisible into subprovinces, depending on the degree to which this fauna invading from the west penetrated eastward. The migration path of the fauna is from the northwest. The "Portage" and "Girard shales" of Erie county, Pennsylvania, are later than Portage time. The "Portage" of Kettle point and adjoining localities—Ontario—is the black shale facies only.

(*c*) The causes of depauperation in Pyrite faunas. Investigations of the organic contents of the sheet of pyrite lying in the horizon of the Tully limestone for a distance of 100 miles in western New York give some clew to the causes which have effected like results in similar occurrences of other age.

(*d*) The determination of the uppermost Cambric in eastern New York, being the discovery of the horizon of Dictyonema and Clonograptus in Rensselaer county.

The fifth and last paper of the morning session was by the same author.

DISTRIBUTION OF MASTODON REMAINS IN NEW YORK

BY JOHN M. CLARKE

[*Abstract*]

About sixty of these occurrences, extending over the period of 1705–1903, have been recorded. This list is of interest in more than one particular. Forty years ago the plains of the west and southwest swarmed with immense herds of buffalo whose bones, left on the ground, have gone as completely as have their bodies. The dry air and arid soil have reduced to dust millions of these skeletons. In the moist and cold climate of the postglacial east, where the mastodon must have traversed New York in much the same abundance as the buffalo did the west, the water-soaked soil has preserved now and again a skeleton of this race. Not every *Mastodon americanus* ended his days in a peat bog. It is noted that these occurrences, specially when considerable parts of the skeleton have been found, are in the swamps and bogs of floodplains and beaches which were river bottoms in the high water period succeeding the ice. The fall of the water, with other conditions, reduced these bottoms to pools on which vegetation gradually encroached, but neither they themselves nor their contents can be of very ancient date. In several instances the bones are found lying beneath the peat upon a coarse stone pavement which indicates the existence there at a former date of a strong water-course. We can not safely deny the presence of the mastodon here during the early period of high water, but may conclude that he remained till a comparatively recent date, when the floods had begun their retreat to their present confines.

Worthy of notice also is the distribution of these skeletons. In two regions of the state they have proved specially numerous. Orange county leads as the home of mastodon remains with a record of 24, more or less, complete skeletons. The lower Hudson Valley counties—Sullivan, Orange, Ulster, and Greene—afford 34 records. The region covered by Monroe, Ontario, Genesee, Livingston, Orleans, and Wyoming counties records 14 skeletons or parts thereof. These two regions were evidently the feeding grounds of the mastodon, possibly its breeding places. The series of swamps in the long Appalachian valleys of Orange and adjoining counties runs southward into New Jersey, and there the bones are also found with frequency. Throughout the belt or territory between the Delaware river on the east and eastern Tompkins county on the west, a distance for about 100 miles, and thence north and south across the state, no single instance of the presence of these remains is shown by the record. This can not be due to the fact that swamps and pools have not existed over this region, but must be ascribed to the gregarious habits of the animals and to the fact that some inducement brought them together in the other regions. But while western New York is a region of salt licks, and the central region equally so, the lower Hudson presents no such inducements.

The two papers of Doctor Clarke were discussed by A. C. Lane, E. R. Buckley, G. F. Wright, Bailey Willis, T. C. Chamberlin, J. C. Merriam, and H. M. Ami.

After announcement by Mr C. W. Hayes that the Photographic Laboratory of the Geological Survey was open for inspection of the Fellows, and by the Secretary concerning the order of future papers, the Society adjourned at 12.35 for the noon recess.

At 2 p. m. the Society was called to order, and Mr G. P. Merrill made announcement of a reception at the United States National Museum on Thursday evening.

The first paper of the afternoon session was

PERMIAN ELEMENTS IN THE DUNKARD FLORA

BY DAVID WHITE

[*Abstract*]

The Dunkard formation or "series," earlier known as the Upper Barren Measures (xvi), embraces the uppermost Paleozoic sediments in the Appalachian trough. It occupies a large area in southwestern Pennsylvania, eastern Ohio, and northern West Virginia, its greatest thickness, in the last named state, being probably over 1,200 feet. The formation is composed of sandstones, shales, thin limestones, and numerous coals. The rocks differ very little from those of the preceding (Monongahela, xv) formation, the chief though not important distinctions being an increase, on the whole, in the arenaceous elements and a more widespread occurrence of the red or brown color in the shales and finally in the sandstones.

The organic remains found in the Dunkard are confined to land and fresh water forms, marine conditions having terminated in this portion of the great trough at about the time of the Crinoidal limestone, near the middle of the Conemaugh (xiv). The fossils consist of land plants, insect remains, seldom identifiable fish fragments, rarely present Unionideæ, and numerous Entomostraceæ. The two latter groups, though promising much of interest, are unstudied. The determination of the age of the beds rests therefore on the evidence of the floras.

Fossil plants in large numbers were collected at several localities and described in 1880, by Professors William M. Fontaine and I. C. White in Report of Progress PP of the Second Geological Survey of Pennsylvania. Of the 107 species and varieties therein described 72 were new and unknown elsewhere, while of the remaining 35 species 22 were listed as common to the Coal Measures of the United States, and 28 as coming from the Permian of Europe. From the study of the composition of the flora and the sedimentation in the basin, the authors reached the conclusion that the entire "Upper Barren Measures" were Permian. This conclusion has been seriously questioned by many geologists and paleontologists on account of the paucity of genera and species characteristic of the Permian of Europe, the large portion of Coal Measures types, and the similarity as well as continuity in the sedimentation. To the writer the correlation with the Permian has seemed doubtful

on account of the small number of characteristic Permian types and the discovery, in the Monongahela, of many of the species previously unknown outside of the Dunkard, thus increasing the proportion of species common to the Monongahela. Furthermore, more than half of the 28 Dunkard species listed as occurring in the European Permian are as common or more common in the Coal Measures both in Europe and in America.

During the summer of 1902 the writer had the opportunity to examine the very interesting types described in the Pennsylvania report, as well as to make collections at new localities and horizons in the formation. The results are a better recognition on his part of a number of important forms insufficiently or poorly reproduced in the report, and the discovery of several characteristic Permian species not previously known in the formation.

To summarize the evidence as to age, the plant material of correlative value as yet brought to light from the Dunkard may be grouped in five categories:

(*a*) Species characteristic of the Rothliegende or higher formations of the old world; (*b*) species closely allied to Permian types; (*c*) species whose habit or facies suggest a late date; (*d*) species of Mesozoic aspect, and (*e*) Coal Measures types.

The species which may be considered as in general characteristic of the Dyas include—

Callipteris conferta Sternb. (typical), *C. lyratifolia* Goepp. var. *coriacea* (F. and I. C. W.), *C. curretiensis* Zeill., *Goniopteris newberriana* (= *Pecopteris fœminæformis* (Schloth.) Sterz. var. *diplazioides* Zeill.), *Pecopteris germari* Weiss, *Alethopteris gigas* Gutb., *Odontopteris obtusiloba* Naum., *Caulopteris gigantea* F. and I. C. W., *Equisetites rugosus* Schimp., *Sphenophyllum fontaineanum* S. A. Mill., *S. tenuifolium* F. and I. C. W., and *Sigillaria approximata* F. and I. C. W.

Among the forms closely allied to species from the old world Permian are—

Odontopteris pachyderma F. and I. C. W. (cf. *Diplothmema ribeyroni* Zeill.), *Cymoglossa obtusifolia* F. and I. C. W., *Goniopteris elliptica* F. and I. C. W., *Pecopteris asplenioides* F. and I. C. W., *P. rarinervis* F. and I. C. W. (cf. *P. pinnatifida* Gutb.), *P. schimperiana* F. and I. C. W. (cf. *P. bredovii*), *P.* [*Callipteridium ?*] *dawsonianum* F. and I. C. W. sp. (cf. *P. fruticosa* Gutb.), *P.* [*Callipteridium ?*] *odontopteroides* F. and I. C. W. sp. (cf. *P. pseudo-bucklandi* Andrä.), *Alethopteris virginiana* F. and I. C. W. (cf. *Callipteridium subelegans* Pot.), *Odontopteris nervosa* F. and I. C. W., *Odontopteris* n. sp. ?, and *Neuropteris flexuosa* var. *longifolia* F. and I. C. W. (probably varietally referable to *N. planchardi* Zeill.).

The above list may be extended according to the amount of comparison and the personal equation of the paleontologist, but evidence of this class is unreliable and of subordinate value at best and will not be further considered at this time. It will be noted that several of the species in this list are properly placed also in the following lists.

Considerable weight as collateral evidence may be ascribed to species which, though not yet reported from any other region, are of such aspect or facies of development as to strongly suggest a period of existence later than the Coal Measures floras. Such forms suggestive of later date for the Dunkard are—

Sphenopteris acrocarpa F. and I. C. W., *S. hastata* F. and I. C. W., *S. minutisecta* F. and I. C. W., *Cymoglossa breviloba* F. and I. C. W., *C. formosa* F. and I. C. W., *Pecopteris goniopteroides* F. and I. C. W., *P. heeriana* F. and I. C. W., *P. subfalcata* F. and I. C. W., *P. merianopteroides* F. and I. C. W., *P.* [*Callipteridium ?*] *unitum*

F. and I. C. W. sp., *P. angustipinna*, *P. lanceolata*, *Equisetites elongatus* F. and I. C. W., and *Cordaites crassinervis* F. and I. C. W.

Several of the species in the preceding list might be placed in the latter category. However, it must not be forgotten that these are perhaps purely American species, some of which may be found common to the as yet but partially known floras of the Monongahela and Conemaugh.

An argument for Permian age that is at once important and interesting is offered in the presence in the Dunkard of a number of types or forms whose seemingly nearest relatives are Mesozoic or whose facies or details strongly suggest types characteristic of the Mesozoic. The most striking of these plants are *Equisetites striatus* F. and I. C. W., resembling the Mesozoic Equisetum; *Nematophyllum angustum* F. and I. C. W., compared by the authors with Schizoneura; a variety of *Pecopteris dentata* Brongn., forcibly suggestive of Thyrsopteris; *P.* (*Callipteridium*?) *odontopteroides* F. and I. C. W. sp., which has a Cladophlebis habit and aspect; *Sphenopteris pachypteroides* F. and I. C. W.; *S. pachynervis* F. and I. C. W.; *Saportæa*, especially *S. grandifolia* F. and I. C. W.,* which seems to lean as much toward the Mesozoic Ginkgo group as toward Rhipidopsis; *Jeanpaulia* (*Boicra*) *virginiana* (F. and I. C. W.), a generic type generally characteristic of the Trias, though present also in the Rothliegende, and *Tæniopteris newberryana* F. and I. C. W., a singular form comparable to *T. coriacea* Goepp., but which might well stand as type of a new genus, probably belonging to the Mesozoic group of large-pinnuled Marattiaceous forms.

Invincibly against the reference of the beds to a level above the basal Permian stands the reported presence of a considerable element of Coal Measures species in the Dunkard. Many of these species are of common occurrence in the Allegheny formation, though others belong more properly to the higher Coal Measures. The number of such species, given by the authors as 22, is now known to be much greater, since the study of the Monongahela flora, though but partially accomplished, shows a large number of plants described from the Dunkard to be also present in the older formation. Among the species more common in the Coal Measures are—

Pecopteris dentata Brongn., *P. emarginata* (Goepp.) Presl.,* *P. elegans* (Goepp.) Germ., *P. arguta* Sternb., *P. pennæformis* Brongn., *P. arborescens* (Schloth.) Brongn.,* *P. oreopteridia* (Schloth.) Sternb.,* *P. Miltoni* (Artis) Brongn., *P. candolleana* Brongn.,* *P. pteroides* Brongn.,* *P. Pluckenetii* Bongn.,* *P.* [*Callipteridium ?*] *grandifolium* F. and W. sp., *Neuropteris fimbriata* Lx., *N. Flexuosa* Sternb.,† *Neuropteris hirsuta* Lx. (form), *N. auriculata* Germ.,* *Aphlebia filiciformis* (Gutb.) Sterz., *Calamites Suckowii* Brongn., *Asterophyllites equisetiformis* (Schloth.) Brongn.,* *Annularia stellata* (Schloth,) Wood,* *Ann. radiata* Brongn., *Ann. sphenophylloides* (Zenk.) Gutb.,* *Sphenophyllum filiculme* Lx.,* *S. longifolium* Germ.,* *S. oblongifolium* Germ.,* and *Sigillaria brardii* Brongn.

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* The two species of *Saportæa* are probably still more closely related to *Noeggerathia dispar* Dawson, from the Coal Measures of Nova Scotia.

* The species marked by the asterisk (*) are reported in the lower Rothliegende, though they are more common in the older formations.

† The species described under this name by Fontaine and White does not represent the plant described by Sternberg. It is related to *N. ovata Hoffm.* The *Neuropteris flexuosa* var. *longifolia* F. and W. of the Pennsylvania report appears to be but a variety of *N. planchardi* Zeill., from the topmost Coal Measures and Lower Rothliegende of Europe and may be designated as the variety *longifolia* of the latter species.

The above list might be largely increased from the species found in the Monongahela formation. The species quoted are, however, among the more widespread Coal Measures types. Over one-half of their number are common plants in the Allegheny or Conemaugh formations.

The Dunkard plants indicate the presence in the Appalachian trough of a transition from the Coal Measures to the typical Permian floras. Such a transition in the plant life is only natural in a region where the terrestrial conditions continued essentially the same, and where there was uninterrupted deposition with but slight and very gradually introduced changes in the sedimentation. The circumstances were most favorable for the persistence of species, and it is therefore not suprising that we find modified representatives of such common Coal Measures types as those recorded in the report under *Neuropteris hirsuta*, *N. flexuosa*, and *Annularia sphenophylloides* continuing in the greatest abundance to the top of the formation. The conditions being continuity of sedimentation, with but slight and gradual physical changes, accompanied by a transitional flora, it is proper to assume that any changes in the flora would be chiefly the results either of climatic modification or of migration from some region experiencing more pronounced physical changes. The determination of the boundary between the Coal Measures and the Dyas is therefore to be governed by the appearance in the region of characteristic Rothliegende species rather than by the presence of persistent Coal Measures types.

As the stages are now generally characterized paleobotanically in western Europe, the presence of representatives of the genus Callipteris, the simple-fronded Tæniopteris, Callipteridium of the types gigas or regina, and the genus Walchia, in a flora largely composed of types common also to the Coal Measures, is regarded as sufficient evidence of Rothliegende age, although *Callipteris conferta* and rare examples of Walchia may occur in the preceding stage. In the Appalachian region *Callipteris conferta* has not yet been found below the Lower Washington limestone, about 175 feet above the base of the Dunkard, where a small variety is present along with a form of *C. lyratifolia*, while the larger, typical form and *C. curretiensis*, together with *Callipteridium gigas* and *Odontopteris obtusiloba*, are not yet known below the Dunkard coal.

The evidence of Rothliegende age for the beds below the Washington limestone consists chiefly in the presence of *Equisetites rugosus* and the less important, though at least to some extent characteristic, *Goniopteris newberryana*, *Pecopteris germari*, *Caulopteris gigantea*, *Sphenophyllum fontaineanum*, and *Sigillaria approximata* in the roof of the Waynesburg coal, at the base of the formation. To this is to be added the occurrence at this level of the special types of Mesozoic or Permian aspect, especially the *Equisetites striatus*, the two species of Saportæa, the Baiera, the lobed Tæniopteris, as well as the *Pecopteris pachypteroides*, *P. dentata* var., and *P.* [*Callipteridium ?*] *unitum*. To these might also be added the species of later facies or affinities listed in the earlier part of this summary. However, the weight of the latter evidence is possibly counterbalanced by the remarkable rarity of all but the last mentioned species, none of which has yet been found elsewhere than in a portion of a single one of the numerous drifts about Cassville, West Virginia, although careful search for them has been made in the same and higher horizons at Cassville and other localities.

On account of the small number of species which may be considered as in a measure characteristic of the Rothliegende, the absence from the latter of Callipteris, the old world Dyassic Odontopteris and Callipteridium, and the extreme

rarity of the types of later facies, it appears that the beds below the Lower Washington limestone can not yet be regarded as conclusively referable to the Rothliegende, though they contain a flora which is certainly transitional. The re-enforcement of this flora at the levels of the Washington and Dunkard coals by the more important and distinctly characteristic Rothliegende species mentioned above seems to fully justify the reference of the latter to the Rothliegende, the lower boundary of which may probably be safely drawn as low as the Washington limestone, which is as yet the lowest observed Callipteris horizon. Further search in the floras of the lower beds of the Dunkard and in the Monongahela is necessary before the upper boundary of the Coal Measures can be definitely ascertained. The flora of the upper portion of the Dunkard is to be compared with those of the Stockheim and Cusel beds in Germany and of the series in the basin of Brives in France.

It is notable that none of the characteristic coniferous genera, Ullmannia, present in the Upper Rothliegende, or Tylodendron and Walchia, the latter of which descends into the top of the Coal Measures, has yet been found in the Dunkard, although all are reported in Prince Edward island, and Walchia is said to occur in the Permian of Texas. No trace of the very large-lobed Odontopterids of the Wangenheimi type and the connate lobed Callipteris species of the Russian Permian or of the genera Plagiozamites, Pterophyllum, and true Dicranophyllum, which occur in the Rothliegende of most of the European basins, has yet been found in the Appalachian trough.

Our highest Appalachian Paleozoic beds do not appear, so far as yet studied paleobotanically, to extend above the Lower Rothliegende of western Europe. The Zechstein, if originally present, as seems not unlikely, has long since disappeared. The reference of the greater part of the Dunkard to the Lower Rothliegende appears to be well founded; but it seems to the writer as probable that the plants of the Upper Dunkard or of the lowest of the terranes of western Europe that are now generally classed as Rothliegende are hardly of so late a date as the flora of the Artinsk stage of Russia.

Remarks were made by I. C. White, G. C. Martin, and the author.

The second paper was received from the list of Section E.

AN IMPORTANT BUT NOT WELL KNOWN LOCALITY FURNISHING CRETACEOUS FISHES

BY O. P. HAY

[*Abstract*]

This paper called the attention of geologists and collectors to a locality in the region about Yankton, South Dakota, from which Dr F. V. Hayden obtained several species of fossil fishes for Professor E. D. Cope. Most of the genera are related to or identical with genera from mount Lebanon, Syria.

The third and fourth papers were presented together, as follows:

STUDIES OF THE GRAIN OF IGNEOUS INTRUSIVES

BY A. C. LANE

PORPHYRITIC APPEARANCE OF ROCKS

BY A. C. LANE

The two papers are printed as pages 369–406 of this volume.

The fifth paper was

PLUMOSE DIABASE CONTAINING SIDEROMELAN AND SPHERULES OF CALCITE AND BLUE QUARTZ

BY B. K. EMERSON

Remarks were made by A. C. Lane and F. B. Peck.

The sixth paper was

CONFIGURATION OF THE ROCK FLOOR OF THE VICINITY OF NEW YORK

BY W. H. HOBBS

The paper was discussed by J. F. Kemp, Bailey Willls, J. W. Spencer, and the author. An abstract is printed in Science, volume xvii, page 298.

The seventh paper was

SUBMARINE VALLEYS OFF THE AMERICAN COAST AND IN THE NORTH ATLANTIC

BY J. W. SPENCER

The paper is printed as pages 207–226 of this volume.

The next two papers, by the same author, and the last ones presented on Wednesday, were received from Section E.

THE BLUE RIDGE OF NORTH CAROLINA

BY W. M. DAVIS

[*Abstract*]

The "Blue Ridge" in northern North Carolina and southern Virginia is not properly a ridge with strong slopes descending on either side of its crest line, but an escarpment separating an uneven and often mountainous upland on the northwest from a rolling and occasionally mountainous lower land on the southeast. The escarpment is not determined by variation of structure in the disordered schists in which it is carved, but by the unequal length of the rivers which drain the upland back of it on the northwest and the lower land in front of it on the southeast. The high-level headwaters of the northwestern rivers, which discharge via the Mississippi into the gulf of Mexico, are constantly losing length by the retreat of the escarpment through the retrogressive erosion of the low-level headwaters of the shorter Atlantic streams. There is no local indication that the sea has had any share in producing the escarpments.

Remarks were made by R. D. Salisbury. The paper is published in the Bulletin of the Geographical Society of Philadelphia.

FRESH-WATER TERTIARIES AT GREEN RIVER, WYOMING

BY W. M. DAVIS

[*Abstract*]

An account of some detailed observations on the stratigraphy of the Tertiary series at Green river, showing the occurrence of variable deposits, including frequent card-board shales alternating with cross-bedded, ripple-marked sandstones and with occasional shale-pebble beds. An inquiry into the nature of strata deposited in large lakes and on the stream-washed surface of interior basins. Conclusion: The Green River Tertiaries are not simply the continuous deposits of a single large lake, but represent the deposits of many successive shallow and fluctuating lakes of moderate area combined with the deposits of numerous aggrading streams.

Remarks were made by Willis T. Lee, a visitor.

The Society then adjourned. No evening session was held, but the Fellows, with ladies and guests, had the annual dinner at the hotel Raleigh.

Session of Thursday, January 1

The Society convened at 9.30 a m; President Winchell in the chair.

The first paper of the session was received from Section E, entitled

PHYSIOGRAPHIC BELTS IN WESTERN NEW YORK

BY G. K. GILBERT

The paper was discussed by Frank Leverett, A. P. Coleman, M. L. Fuller, A. P. Brigham, and A. W. Grabau. A short abstract is printed in Science, volume xvii, page 221.

The President called H. S. Williams to the chair, and the second paper was read by Professor Kemp.

LEUCITE HILLS OF WYOMING

BY W. C. KNIGHT AND J. F. KEMP

The paper was discussed by Bailey Willis, S. F. Emmons, and G. K. Gilbert. It is printed as pages 305–336 of this volume.

Vice-President S. F. Emmons assumed the chair, and the administrative business of the day was taken up. The Secretary stated that the American Association for the Advancement of Science had decided to not hold a summer meeting in 1903. This produces a condition not anticipated nor provided for in the rules of the Society. The Council therefore recommended that the Society give the Council power to make decision as to the summer meeting. The Society adopted the recommendation.

REPORT OF THE AUDITING COMMITTEE

Mr J. S. Diller presented the report of the Auditing Committee as follows :

To the Geological Society of America :

We have the honor to report that we have examined the accounts of Dr I. C. White, Treasurer of the Society, including the bank books, official checks, and itemized bills of expense, and have found them correct, as stated in his report to the Council.

Very respectfully,

ARTHUR KEITH,
J. S. DILLER,
Auditing Committee.

The report was adopted.

The report of the Committee on Photographs was read by the Secretary as follows :

THIRTEENTH ANNUAL REPORT OF THE COMMITTEE ON PHOTOGRAPHS

During 1902 the Committee has completed the catalogue of the collection of photographs and it is now in course of publication as a brochure of the Bulletin, volume 13. This catalogue consists of a list of the photographs, arranged alphabetically by states and countries, and a classified subject index. In the list are given the numbers of the negatives of the many photographs from the United States Geological Survey, which will aid greatly in ordering prints. The collection is stored in the building of the Geological Survey, where it is convenient of access at all times.

Respectfully submitted.

N. H. DARTON,
Committee.

The report was adopted and the usual appropriation of $15 for the use of the committee was voted.

COMMUNICATION TO THE HOUSE OF REPRESENTATIVES CONCERNING THE APPALACHIAN FOREST RESERVE

The Secretary presented a recommendation from the Council that the following address and resolution, offered by Professor J. A. Holmes, be adopted, and that a special committee, consisting of the President of the Society and Professor Holmes, with power to add to their number, be appointed to present the communication to the Speaker of the House of Representatives.

To the Speaker, House of Representatives, Washington, D. C.

SIR: The geologists of this country have for many years shown an active interest in the preservation of forests as a means of perpetuating the regular flow of streams in the interest of navigation, waterpower, and agricultural developments, and of protecting land surfaces on mountain slopes.

In connection with the vitally important measure now before Congress, which provides for the establishment of a national forest reserve among the southern Appalachian mountains,, the members of the Geological Society beg to call attention to the facts:

That the numerous lakes, marshes, and gravel deposits which in the more northern states serve to regulate the flow of the streams are entirely absent from this southern mountain region;

That the grass sod which northward retards the washing away of the soil on slopes cleared of their forests on these southern mountains does not exist sufficiently to serve this useful purpose;

That in this southern Appalachian region the forest is the only agency that can prevent the rapid and destructive erosion of these mountain slopes by the heavy rains and the silting up of the streams having their sources in this region;

That these forests and the soil which they hold in place are the only agencies in this region which can regulate the flow of these streams, thus serving to protect their waterpowers and navigation and to prevent the destructive floods which, with increasing frequency and violence, are destroying not only the high lands of the mountain region, but also the lowland farms along all these rivers for hundreds of miles, across more than half a dozen states, and which floods will undoubtedly increase as the forest destruction continues.

The above facts, considered in connection with the steepness of these mountains and the excessively heavy and irregular rainfall on their slopes, render certain the early and complete ruin of this valuable portion of our country if this present policy is continued.

These facts, together with the extent and importance of the streams and the number of states involved, makes this measure stand alone before the country as a national problem and a national necessity.

Resolved, That the Geological Society of America therefore respectfully asks that the Senate bill (5228) now on the calendar of the House of Representatives, providing for the establishment of a national forest reserve in the southern Appalachian region, be brought before the House for action upon it before the end of the present session of Congress;

Resolved, That the Geological Society of America further respectfully petitions the House of Representatives to act on this measure promptly and favorably, in

order that the present rapid destruction of the forests of that region may be stopped without delay.

Passed by the Geological Society of America January 1, 1903, and ordered presented to the Speaker of the House of Representatives by the committee named below.

S. F. Emmons, *President.*
Herman L. Fairchild,
Secretary.

Committee:

T. C. Chamberlin, Chicago, Illinois.
S. F. Emmons, Washington, D. C.
Israel C. Russell, Ann Arbor, Michigan.
I. C. White, State Geologist, West Virginia.
N. H. Winchell, Minneapolis, Minnesota.
C. R. Van Hise, Madison, Wisconsin.
W J McGee, Washington, D. C.
W. B. Clark, State Geologist, Maryland.
C. H. Hitchcock, Hanover, New Hampshire.
H. L. Fairchild, Rochester, New York.
J. A. Holmes, Saint Louis, Missouri.
E. R. Buckley, State Geologist, Missouri.

The recommendation of the Council was voted.

The scientific program was resumed and the third and fourth papers of the session, which were received from Section E, were read and discussed as one.

ORIGIN OF THE SAND HILL TOPOGRAPHY OF THE CAROLINAS

BY COLLIER COBB

RECENT CHANGES IN THE NORTH CAROLINA COAST, WITH SPECIAL REFERENCE TO HATTERAS ISLAND

BY COLLIER COBB

The papers were discussed by W. M. Davis, I. C. Russell, G. K. Gilbert, and the author. Short abstracts are printed in Science, volume xvii, pages 226, 227.

The two following papers were also received from Section E:

TOPOGRAPHIC WORK OF THE GEOLOGICAL SURVEY IN NORTHERN CANADA

BY ROBERT BELL

An abstract is printed in Science, volume xvii, page 221.

SCIENTIFIC RELIEF MAPS

BY G. C. CURTIS

The subject of the latter paper was discussed by C. W. Hayes, W. M. Davis, and the author. A short abstract is printed in Science, volume xvii, page 222.

The Society adjourned for the noon recess, following which Mr Norman W. Carkhuff, in charge of the Photographic Laboratory of the Geological Survey, gave a demonstration of the process and instrument for "daylight development" of kodak films.

The Society reconvened at 2.10 p m.

The first paper of the afternoon session was the following:

ORIGIN OF OCEAN BASINS ON THE PLANETESIMAL HYPOTHESIS

BY T. C. CHAMBERLIN

[*Abstract*]

The planetesimal hypothesis of the origin of the solar system differs fundamentally from the Laplacian and other gaseous hypotheses, and from the meteoroidal hypothesis as set forth by Lockyer and Darwin. These latter assign the extension of the parent nebula to the opposed movements, collisions, and rebounds of the constituent molecules or meteoroids. The former assigns it to concurrent orbital movement. In the gaseous and meteoroidal hypotheses (as usually understood) the aggregation is the simple work of gravity following a reduction of the oscillatory and colliding action. In the planetesimal hypothesis the aggregation is dependent on orbital conjunction. In the former the aggregation is massive and relatively rapid; in the latter the aggregation is individual and relatively slow. In the gaseous hypothesis the temperatures are necessarily very high, and the planets are formed by detachments. In the meteoroidal conception of George Darwin, the conditions are practically the same, and in that of Lockyer they differ rather in degree and in detail than in essence. In the planetesimal conception the planets grew up separately by innumerable accretions of infinitesimal planetoids (planetesimals), and the external temperatures were not necessarily high, since the orbits of the planetesimals were normally direct and concurrent and the aggregation came about by overtakes in contradistinction to opposed collisions, and the frequency of these was limited by the concurrent direction of orbital movement.

The paper outlined the hypothetical origin of the ocean basins under the planetesimal theory, and set forth the simple self-selecting process by which they were perpetuated and deepened, and the connection of this with the dynamics of deformation.

The paper was discussed by A. C. Lane, H. F. Reid, G. P. Merrill, G. K. Gilbert, G. F. Becker, Bailey Willis, and the author.

The second paper was received from Section E, entitled:

LUNAR CALDERAS

BY MISS E. HAYES

Remarks were made by Whitman Cross and T. C. Chamberlin. A short abstract is printed in Science, volume xvii, page 222.

The three following papers, by the same author, were presented without discussion, the second one being read by title:

RECENT VOLCANIC CRATERS IN IDAHO AND OREGON

BY ISRAEL C. RUSSELL

[*Abstract*]

Four groups of craters were described, namely, the Cinder Buttes, Idaho, and the Diamond, Jordan, and Bowden craters, Oregon. The craters in each of these groups are remarkably fresh and furnish typical examples of both cinder cones and "lava cones." Vast volumes of lava were poured out from each of the groups of craters, which at the time of its extrusion was highly liquid, but became exceedingly viscous as it slowly cooled. Illustrations were shown of cinder cones, lava cones, driblet cones or "ovens," lava "gutters," a large variety of volcanic bombs, dunes of lapilli, large fragments of tuff derived from cinder cones ruptured by escaping lava and floated on the lava streams, islands in lava streams, characteristic features of the surfaces of lava streams, etcetera.

The paper was an abstract from a report since published in Bulletin number 217 of the U. S. Geological Survey.

LAKES MALHEUR AND HARNEY, OREGON

BY ISRAEL C. RUSSELL

[*Abstract*]

These lakes furnish an instructive example of the manner in which a water body has been divided by the formation of sand dunes, and of the overflow of one alkalin lake into another, so as to lead to the freshening of the former and the concentration of the latter.

This paper was an abstract of a report since printed as Bulletin number 217 by the U. S. Geological Survey.

ARTESIAN WELLS NEAR ENTERPRISE, IDAHO

BY ISRAEL C. RUSSELL

[*Abstract*]

The wells referred to are situated in the Lewis artesian basin, and from their increase in temperature as a large hot spring as Enterprise is approached, it seems

evident that they are supplied, in part, at least, with water which rises through deep fissures in the rocks beneath the artesian basin.

This paper was an abstract of a report since printed by the U. S. Geological Survey as Water-Supply and Irrigation Paper number 78.

The next paper was

NORTHWARD FLOW OF ANCIENT BEAVER RIVER

BY RICHARD R. HICE

Remarks were made by I. C. White and M. R. Campbell. The paper is printed as pages 297–304 of this volume.

The following paper was then read:

CONCRETIONS AND THEIR GEOLOGICAL EFFECTS

BY J. E. TODD

The paper is printed as pages 353–368 of this volume.

The last paper of the day was the following:

CLASTIC DIKES

BY J. F. NEWSOM

The paper is printed as pages 227–268 of this volume.

The Secretary announced that the Council had arranged to hold no session of the Society on Friday morning, thus giving opportunity for Section E, American Association for the Advancement of Science, to hold a session for the reading of its papers on the West Indies, but that the Society would meet Friday afternoon at 2 o'clock. The Society then adjourned.

Session of Friday, January 2

The Society was called to order at 2.15 o'clock p m by Dr I. C. White.

The Secretary announced that the Council had considered the matter of future meetings and had decided to not hold any summer meeting of the Society this year, and to hold the winter meeting the last week in December in St Louis, Missouri, in conjunction with the American Association for the Advancement of Science.

The scientific program was taken up, and the following three papers were read in order and discussed as a unit:

ORIGIN OF BASIN RANGES

BY G. K. GILBERT

[*Abstract*]

Fresh interest in the origin of the Basin ranges having been aroused by Mr Spurr's communication to the Albany meeting of the Society, the writer spent the summer of 1901 in the study of certain ranges of western Utah. The paper discussed the origin of these as indicated by their physiography and structure, and considered the nature of the evidence bearing on such questions.

Evidence of block faulting was shown to exist in extensive shear zones, in triangular facets terminating the ridges in front, and in the even linear bases of the ranges. That the faulting is still going on is shown by displacements in the recent alluvium.

BLOCK MOUNTAINS OF THE BASIN RANGE PROVINCE

BY W. M. DAVIS

[*Abstract*]

Observations of several of the Basin ranges in the summer of 1902 support the opinion of Gilbert, Russell, and others that the ranges observed are carved in uplifted or tilted blocks of earth crust that had been previously much deformed and eroded. The faulting of the crustal blocks has been continued into recent geological time. The amount of erosion during the progress of faulting has been so great that the pre-fault topography can not be safety determined.

BASIN RANGE STRUCTURE IN THE DEATH VALLEY REGION OF SOUTHEASTERN CALIFORNIA

BY M. R. CAMPBELL

[*Abstract*]

Recently attention has been called to the geologic structure of the mountain ranges of Nevada and southeastern California. An attempt has been made to show that they are generally anticlinal in structure, and that the tilted block type which Gilbert has described and which is generally known as Basin range structure, is of rare occurrence.

The object of the paper is to show that, although minor folding was observed in the Death Valley region, the mountains are generally composed of huge blocks of strata that have been strongly tilted and then eroded into their present forms.

The region described is traversed by two systems of structures—one extending in a north-south direction, being the southern extension of the true basin ranges of Nevada, and the other crossing these in a northwest-southeast direction parallel with and presumably an offshoot from the main line of the Sierra Nevada. The movements which produced these structures seem to have been preceded by an epoch of slight folding in which the Paleozoic strata were somewhat deformed. This was followed presumably in Eocene time by faulting and tilting along the northwest-southeast axes which formed parallel mountains and valleys trending n the same direction as the Sierra Nevada. In the valleys so formed lakes accu-

mulated, probably through a change in climatic conditions, and sediments having a thickness of several thousand feet were laid down. In these lake beds are the great deposits of salt, gypsum, soda, and borax which have made the region famous. Following this period of sedimentation came one of movement along the north-south axis, which lifted and tilted the surface into immense mountain ranges trending parallel with the new axes. Panamint, Death, and Amargosa valleys were thus formed, and Funeral and Panamint mountains were raised up between them. Lakes formed in the new valleys and received sediments similar to those of the preceding period.

The age of the second lake forming period is vaguely referred to late Tertiary. From structural and stratigraphic evidence the beds are younger than the lake sediments of Death valley, and they are certainly older than the gravel deposits which mark the Pleistocene period in this region; therefore they are provisionally classed as Miocene and younger.

The subject of the three papers, "Basin Range Structure," was discussed by C. R. Van Hise, S. F. Emmons, and Doctor Gilbert.

Doctor White asked Professor H. S. Williams to take the chair, and the fourth paper read was

INSTRUMENTS FOR OBSERVATION OF DISTURBANCES CAUSED BY DISTANT EARTHQUAKES

BY H. FIELDING REID

The fifth paper was read by title, the author placing on the table for distribution copies of a similar paper published in the Transactions of the American Institute of Mining Engineers.

STRUCTURAL SECTION ACROSS THE SIERRA MADRE OF MEXICO

BY W. H. WEED

The sixth paper was received from the Section E list:

HIGHLY VISCOUS ERUPTION OF RHYOLITE

BY G. K. GILBERT

Remarks were made by A. C. Lane.

The following four papers were read by title:

RELATION BETWEEN THE KEEWATIN AND LAURENTIDE ICE SHEETS

BY A. H. ELFTMAN

POST-GLACIAL TIME

BY A. H. ELFTMAN

GLACIAL BOULDERS ALONG THE OSAGE RIVER IN MISSOURI

BY E. R. BUCKLEY, S. H. BALL, A. F. SMITH

[*Abstract*]

Glacial boulders have been found at eight localities along the Osage river, in Miller county, Missouri, during the survey of that county last year. These boulders are all igneous, and vary in composition from granite and gneissoid granite to diorite. They are far removed from any outcrops of these rocks, and neither the Osage river nor any of its tributaries pass by or through rocks of this character. Their character and relations to the surrounding formations compel their recognition as glacial boulders.

GLACIAL DRAINAGE IN CENTRAL-WESTERN NEW YORK

BY H. L. FAIRCHILD

[*Abstract*]

Three stages are noted in the drainage from the glacier during its retreat from New York. (1) Flow southward across the divide, at the head of the north-leading valleys. (2) Flow past (alongside) the ice front. (3) Flow directly into the great lakes which laved the ice front.

The paper treats specially of the second stage. It is found that east of Syracuse the iceward-facing slopes were swept by the streams flowing eastward past the glacier front, and that west of the Genesee valley such slopes were scoured by waters flowing westward.

The next paper was read by the author, entitled

GLACIAL FEATURES OF BIG HORN MOUNTAINS

BY N. H. DARTON

Remarks were made by W. M. Davis and R. D. Salisbury.

The next two papers were from the list of Section E.

CRITERIA REQUISITE FOR THE REFERENCE OF RELICS TO A GLACIAL AGE

BY T. C. CHAMBERLIN

The subject was discussed by G. F. Wright, J. E. Todd, B. K. Emerson, and the author. A short abstract is printed in Science, volume xvii, page 223.

FURTHER NOTES ON LAKE ARICKAREE

BY J. E. TODD

A short abstract is printed in Science, volume xvii, page 227.

The next paper was one which had been passed in the Society's program in order to read in connection with the glacial papers.

MARL-LOESS OF THE LOWER WABASH VALLEY

BY M. L. FULLER AND F. G. CLAPP

The paper is printed as pages 153–176 of this volume.

Discussion was postponed until the next paper was read, which was from the Section E list.

PROBLEM OF THE LOESS IN THE MISSOURI VALLEY COMPARED WITH THAT IN EUROPE AND ASIA

BY G. FREDERICK WRIGHT

The two papers were discussed by T. C. Chamberlin, J. E. Todd, N. H. Winchell, and M. L. Fuller.

The paper by Mr Wright is printed in abstract in Science, volume xvii, page 227.

The succeeding paper was also from the Section E list.

NEW METEORITE ("BATH FURNACE") FROM SALT LICK, KENTUCKY

BY A. M. MILLER

A short abstract is printed in Science, volume xvii, page 228.

The following eight papers, which had been laid over on account of the absence of the authors, were read by title.

CAMBRIAN AND PRE-CAMBRIAN OF HOOSAC MOUNTAINS, MASSACHUSETTS

BY JOHN E. WOLFF

[*Abstract*]

Since the original fieldwork of 1885–1887, the results of which appeared in Monograph 23, United States Geological Survey, the northward extension of this area has been studied, and with experience gained there and elsewhere a revision of Hoosac mountain has been made, somewhat extending the pre-Cambrian areas, which are briefly described. The obscure relations of the pre-Cambrian and Cambrian on the west slope of Hoosac mountain are discussed.

ORDOVICIAN SECTION NEAR BELLEFONTAINE, PENNSYLVANIA

BY GEORGE L. COLLIE

This paper is printed as pages 407–420 of this volume.

STRUCTURAL RELATIONS IN THE PIEDMONT AREA OF NORTHERN MARYLAND

BY EDWARD B. MATHEWS

[*Abstract*]

This paper gives the conclusions reached after a detailed field study of nearly 1,000 square miles in Cecil, Harford, and Baltimore counties, Maryland. It sug-

gests that the structure of the area, while intricate in details, is rather simple in its broader lines, and indicates that the extremely complicated structure inferred by earlier workers is not corroborated by the later and more detailed investigations. It includes a brief discussion of the probable age of the deposits, and suggests that this is Paleozoic and not pre-Cambrian, as formerly supposed, for almost if not all the gneisses.

The paper is published in full in the American Journal of Science, fourth series, volume xvii, February, 1904.

GEOLOGICAL HISTORY OF THE VERMILION IRON-BEARING DISTRICT OF MINNESOTA

BY J. MORGAN CLEMENTS

[*Abstract*]

The Vermilion district has one of the longest geological histories of any region in the world. Since Archean time—represented in this district—there were five great periods of deposition: The Lower Huronian, the Upper Huronian, the Keweenawan, the Paleozoic, and the Cretaceous.

There were four great periods of igneous activity: During Archean time, the great batholithic intrusions at the end of Archean time, the hardly less important batholithic intrusions at the end of Lower Huronian time, and the great Keweenawan period of volcanic extrusion and intrusion. There was also possibly contemporary volcanic activity during Lower Huronian time.

There were five great periods of orogenic movements, denudation, and metamorphism: 1, following the Ely greenstone of the Archean; 2, following the Archean series as a whole; 3, following the Lower Huronian; 4, following the Upper Huronian, and 5, following the Keweenawan.

Also there were three other great periods of denudation, the Cambrian and the Cretaceous periods of baseleveling, and, finally, the period following the Cretaceous, extending to the present time.

SPHERULITIC TEXTURE IN THE ARCHEAN GREENSTONES OF MINNESOTA

BY J. MORGAN CLEMENTS

[*Abstract*]

The occurrence of spherulites, some 2 inches in diameter, in great abundance in the basic and intermediate lavas, "greenstones," of Archean age in northeastern Minnesota are described; also the wide distribution of similar spherulitic greenstones in other districts in the Lake Superior region is emphasized.

NANTUCKET SHORELINES. I

BY F. P. GULLIVER

[*Abstract*]

On account of its exposed position and loose texture the island of Nantucket offers a good field for the study of the development of shorelines. There are many important historical changes, many of which have been well recorded on the

government charts; there are a number of early maps of this coast which are in the main little more than sketches, and yet when these sketches are studied with reference to other facts, interesting inferences may be drawn; there are many traditions of the island and its changing shoreline which are worthy of consideration in a comprehensive study of the development of the island; there are facts in the early history of the island, such as the settlement on Capaum harbor, now a pond, which throw light on the development, and, more than all, there are small changes from year to year in various parts of the island, which if carefully and systematically recorded will throw much light on the past history of the island in the present cycle of its development, and which may also increase our knowledge of the general development of shorelines.

The writer proposes to undertake the study of this island along all of the lines mentioned above, and to report to the Geological Society of America the results of his investigations in a series of papers. The plan of work will be to take up in detail the various points where changes have been made in the past or are made in future years by cutting away or building up, and to publish detailed plane-table maps to show present conditions. These maps may be used for comparison in future years.

The following areas will be taken up in succeeding papers: Great point, Coskata, Haulover break, Squam head, Sankaty head, 'Sconset, Tom Nevers, Nantucket shoals, South shore, Surfside, Maddaket, Smith point, Tuckernuck island, Tuckernuck shoals, Muskeget island, Muskeget shoals, Eel point, Capaum, Brant point, Nantucket harbor, Coatue, Abrams point, Polpis harbor.

After the facts for these areas have been studied, the history of the development of this region in the present cycle will be worked out.

TIMBERLINES

BY ISRAEL C. RUSSELL

[*Abstract*]

"Timberline," as commonly defined, is the upper limit of arboreal vegetation on mountains. Its position is determined mainly by the occurrence of a mean annual temperature of about 32 degrees Fahrenheit, but locally its elevation is regulated by soil conditions, and by differences between various localities in snowfall, severity of winter storms, exposure to the sun, etcetera. It may with propriety be termed the "cold timber-line." Above it, on high mountains, there is commonly a region occupied by alpine flowers, and still higher a region of perpetual snow. When traced from warm to colder regions, or, in general, from equatorial toward polar regions, it becomes lower and lower. In North America it descends nearly to sealevel in Alaska and northern Canada, where it defines the northern limit of the subarctic forest and becomes the "continental timber-line," to the north of which lie the barren grounds and tundras, which correspond to the zone of alpine flowers on lofty mountains in temperate latitudes.

On some of the mountain ranges of the arid portion of the United States there is a lower limit of tree growth, the position of which is determined in the main by insufficient moisture, and locally by soil conditions, including the presence of alkali, hot winds, forest fires, exposure to the sun, etcetera. This may be termed the "dry timber-line." Below it are treeless, grass-covered plains and valleys. On

the mountains of central Idaho, the cold timberline is sharply drawn at an elevation of about 10,000 feet, while the dry timberline, equally well defined, has an elevation of about 7,000 feet; between the two there is a belt of forest trees which encircles the mountains. In southeastern Oregon, Nevada, southern California, etcetera, where the climate is excessively arid, the dry timber-line is higher than in Idaho, and in certain localities meets the cold timberline, and the mountains are bare of trees from base to summit. The dry timberline decreases in elevation when traced from arid to humid regions. In the central part of the continental basin of North America it defines the border of the treeless portion of the Great plateaus and the prairie plains, and at the north coincides with the southern limit of the sub-arctic forest. On the borders of the treeless plateaus and the prairie plains the position of the margin of the encircling forest is determined mainly by lack of moisture, but is varied locally by soil conditions, hot winds, forest fires, etcetera, in the same manner that the lower limit of tree growth on the mountains of arid region is regulated.

When the humidity is sufficient for the growth of trees, as, for example, on the mountains of New England, the dry timberline disappears. An arid region may be bordered at a lower elevation by a region with sufficient humidity to permit trees to grow, and may then be bordered both above and below by the dry timberline, as is the case in southern Idaho. Where an arid region reaches sealevel, as in Arizona, southern California, and the west coast of Mexico, etcetera, there is no forest below the arid belt, and in certain localities the dry timberline meets the cold timberline, and the mountains are bare of trees from sealevel to their summits.

There is also a third general cause which draws a limit to timber growth, namely, excessive humidity, as, for example, on the borders of swamps, the margins of lakes, etcetera, which may perhaps be termed the "wet timberline."

WORK OF THE GEOLOGICAL SURVEY OF CANADA IN 1902

BY ROBERT BELL

[*Abstract*]

The different classes of workers, their numbers: Field work; the parties which were sent out, objects to be attained, means employed; regions surveyed and explored from the Yukon district to Nova Scotia; some of the results. Work relating to mines and economic geology; to chemistry, mineralogy, and petrography; the publication of serial reports and special treatises with illustrations; artists' work; labors of the staff in paleontology, zoology, economic botany, fruit growing. The extension of agriculture in the north, forestry, forest fires, preservation of timber; necessity for topographical surveying in unexplored regions; the compilation and engraving of maps, those published and those in course of preparation during the year; making of illustrative models of sections and surface relief; work in connection with the museum and library; aid given to education, distribution of reports, maps, suits of named specimens of minerals and rocks; the collecting of fossils, rocks, and minerals; the preparation of pamphlets and descriptive catalogues showing the mineral wealth of Canada; displays of economic minerals, etcetera, at international exhibitions; contributions to archeology and ethnology; extensive correspondence of the department, great variety of subjects treated of; infor-

mation and encouragement given to prospectors and explorers; usefulness of the department as a means of introducing producers and consumers to each other and in giving information and advice leading to the establishment of new industries.

The following 12 titles were received from the program of Section E, but the papers were not presented:

GENESIS OF THE AMPHIBOLE SCHISTS AND SERPENTINES OF MANHATTAN ISLAND

BY A. A. JULIEN

The paper is printed as pages 421–494 of this volume.

DIKES IN THE OKLAHOMA PANHANDLE

BY C. A. WALDO

A brief abstract is printed in Science, volume xvii, page 220.

DRAINAGE BASINS OF MINNESOTA—A TYPE OF PHYSIOGRAPHIC YOUTH

BY C. W. HALL

SHORE PHENOMENA OF LAKE HURON

BY M. S. W. JEFFERSON

A short abstract is printed in Science, volume xvii, page 221.

EVIDENCES OF POST-NEWARK NORMAL FAULTING IN THE CRYSTALLINE ROCKS OF SOUTHWESTERN NEW ENGLAND

BY W. H. HOBBS

An abstract is printed in Science, volume xvii, page 223.

RECORD OF POST-NEWARK DEPRESSION AND SUBSEQUENT ELEVATION WITHIN THE AREA OF SOUTHWESTERN NEW ENGLAND

BY W. H. HOBBS

A short abstract is printed in Science, volume xvii, page 223.

GLACIAL CIRQUES AND ROCK TERRACES ON MOUNT TOBY, MASSACHUSETTS

BY B. K. EMERSON

A short abstract is printed in Science, volume xvii, page 224.

PROTECTION OF TERRACES IN THE UPPER CONNECTICUT RIVER

BY C. H. HITCHCOCK

An abstract is printed in Science, volume xvii, page 224.

GLACIATION IN THE BERKSHIRE HILLS, MASSACHUSETTS

BY F. B. TAYLOR

An abstract is printed in Science, volume xvii, page 225.

VALLEY LOESS AND THE FOSSIL MAN OF LANSING, KANSAS

BY WARREN UPHAM

[*Abstract*]

The loess in the Missouri and Mississippi valleys is attributed to deposition by these rivers during a time of somewhat lower altitude of this region, at the beginning of the Champlain epoch, when the glaciated area of this continent sank from its previously high elevation to be mostly 300 to 500 feet lower than now. By this depression a temperate climate was restored on the border of the continental ice-sheet, which became greatly reduced by its surface melting, so that much of the drift before contained within the ice was at last exposed on the thinned ice-fields, as now on the Malaspina ice-sheet in Alaska.

The ice-melting and rains probably swelled these great rivers to twice or three times their present average annual volume; and their supply of silt, brought in abundance by the rills, brooks, and rivers that flowed down from the waning ice-sheet, was very probably fivefold to tenfold more than now. Under these conditions of very abundant silt, rivers swollen to floods throughout the summers, and less current of their sluggish descent to the Gulf, it is estimated that the Iowan stage of chief deposition of the valley loess, gradually building up the river floodplains to heights of 150 to 250 feet above the bottomlands of today, may have occupied only about a thousand years.

During the same time the winds are thought to have blown away much of the loess from the valley floodplains, and from the ice surface, spreading it far and wide as the general sheet of upland loess, mostly 10 to 25 feet thick, mantling the high and low lands upon the great areas between the rivers with a surprising uniformity of thickness. It is evident also that this silt mantle includes some contribution, most considerable westward, of wind-borne dust from the great western plains, this part being not of glacial origin.

After the accumulation of the loess, and before the moraine-forming Wisconsin stage of the waning and wavering glaciation, this region was uplifted 300 to 500 feet, or perhaps somewhat more, on account of the diminution of the ice weight and pressure, thereby giving to the rivers the same steeper gradients and more powerful currents as now. They therefore eroded the valley loess to depths somewhat below the present bottomlands, and sculptured the valleys in nearly their present forms, with high inclosing bluffs of loess, before the moraines of Wisconsin, Minnesota, and northern Iowa were amassed along the ice boundary at pauses of its general retreat.

Again, during this Wisconsin stage much modified drift was borne into the valleys. Its coarser portion of gravel and sand filled the valleys anew to heights of 100 to 200 feet, or more, near the ice border; but the strong river currents, with nearly their present slopes, carried the fine silt, corresponding to the former loess deposit, far down the valleys to the lower Mississippi and the Gulf.

Along the Big Sioux valley, on the northwest boundary of Iowa, a floodplain

of modified drift, associated with the moraines, has an average width of 1½ miles, as described in volume X of the Iowa Geological Survey, and is only about 10 feet above the present relatively insignificant bottomland, which averages about a fifth of a mile in width. Below the junction of the Big Sioux with the Missouri, this floodplain of Wisconsin time continues with a width of 6 to 12 miles on the east side of the Missouri through the distance of 90 miles to Council Bluffs and Omaha, having only the same slight altitude above the river. Southward from the mouth of the Platte river, as I think, the old Wisconsin floodplain was lower than the bottomland today, which has gained in depth, rather than lost, ever since the Ice age. Conditions requisite for silt deposition 30 to 50 feet above the Missouri at Lansing, Kansas, where a skeleton was discovered last February under 20 feet of a deposit which I regard as the original Iowan loess, appear thus not to have existed during the ensuing Wisconsin stage of glaciation, nor during any part of the Postglacial period.

The antiquity of the Lansing man I think to be measured by about 12,000 years or, at the longest, 15,000 years. But men are known to have been living in Europe, and probably they may also have migrated to America, in the early part of the Ice age, or even before it—that is, very surely as long ago as 100,000 years. Therefore the resemblance of the Lansing skeleton to the average type of our American aborigines, called Indians, appears in no degree surprising to one who believes that the creation of plants and animals has proceeded by the gradual methods of generic and specific development which are collectively termed evolution.

This paper is published in full in the American Geologist, volume xxxi, January, 1903, pages 25–34.

HANGING VALLEYS OF GEORGETOWN, COLORADO

BY W. O. CROSBY

An abstract is printed in Science, volume xvii, page 227.

SCIENCE AT THE WORLD'S FAIR, SAINT LOUIS, 1904

BY J. A. HOLMES

A short abstract is printed in Science, volume xvii, page 229.

On motion of the Secretary, the following resolution was adopted :

Resolved, That the hearty thanks of the Society be extended the officials of the United States Geological Survey for provision of rooms and facilities for the very large and successful meeting ; to the local committees on arrangements and dinner, Messrs C. W. Hayes and G. H. Eldridge, chairmen, for their generous efforts in behalf of the meeting; to Mr W. S. Robbins for constant and courteous attention to the desires and wants of the Fellows and officers; to Mrs Charles D. Walcott for the reception tendered the ladies of the Association and the Fellows of the Society, and to the Bausch and Lomb Optical Company of Rochester, New York, for supplying the lantern for the use of the meeting.

At 7.30 o'clock p m the meeting was declared adjourned.

Register of the Washington Meeting, 1902–1903

The following Fellows were in attendance at the meeting:

F. D. Adams.
H. M. Ami.
G. H. Ashley.
Florence Bascom.
W. S. Bayley.
G. F. Becker.
Robert Bell.
A. P. Brigham.
A. H. Brooks.
E. R. Buckley.
H. D. Campbell.
M. R. Campbell.
T. C. Chamberlin.
W. B. Clark.
J. M. Clarke.
Collier Cobb.
A. P. Coleman.
G. L. Collie.
A. J. Collier.
A. R. Crook.
W. O. Crosby.
Whitman Cross.
N. H. Darton.
W. M. Davis.
D. T. Day.
J. S. Diller.
R. E. Dodge.
G. H. Eldridge.
B. K. Emerson.
S. F. Emmons.
H. L. Fairchild.
Persifor Frazer.
M. L. Fuller.
G. K. Gilbert.
A. C. Gill.
L. C. Glenn.
A. W. Grabau.
U. S. Grant.
H. E. Gregory.
Arnold Hague.
C. W. Hall.
J. B. Hatcher.
C. W. Hayes.
Angelo Heilprin.
R. T. Hill.
C. H. Hitchcock.
W. H. Hobbs.
Arthur Hollick.
J. A. Holmes.
T. C. Hopkins.
E. O. Hovey.
E. E. Howell.
J. P. Iddings.
Arthur Keith.
J. F. Kemp.
F. H. Knowlton.
E. H. Kraus.
H. B. Kümmel.
A. C. Lane.
Frank Leverett.
Waldemar Lindgren.
W J McGee.
C. F. Marbut.
G. C. Martin.
W. C. Mendenhall.
J. C. Merriam.
G. P. Merrill.
A. M. Miller.
J. F. Newsom.
W. H. Niles.
F. B. Peck.
R. A. F. Penrose.
G. H. Perkins.
F. L. Ransome.
H. F. Reid.
W. N. Rice.

Heinrich Ries.
I. C. Russell.
R. D. Salisbury.
F. C. Schrader.
Charles Schuchert.
W. B. Scott.
G. B. Shattuck.
G. O. Smith.
W. S. T. Smith.
A. C. Spencer.
J. W. Spencer.
J. E. Spurr.
J. Stanley-Brown.
T. W. Stanton.
J. J. Stevenson.
R. S. Tarr.
F. B. Taylor.
J. E. Todd.
C. R. Van Hise.
T. W. Vaughan.
C. D. Walcott.
H. S. Washington.
T. L. Watson.
W. H. Weed.
L. G. Westgate.
David White.
I. C. White.
H. S. Williams.
Bailey Willis.
S. W. Williston.
A. W. G. Wilson.
H. V. Winchell.
N. H. Winchell.
R. S. Woodward.
J. B. Woodworth.
A. A. Wright.
G. F. Wright.

Fellow-elect

G. I. Adams.

Total attendance, 114.

Session of the Cordilleran Section, Tuesday, December 30.

The fourth annual meeting of the Cordilleran Section was called to order at 10.30 a m, December 30, 1902, in the council-room of the California Academy of Sciences, San Francisco.

In the absence of the Chairman of the Section, Dr H. W. Fairbanks was elected temporary chairman.

The minutes of the last meeting were read and approved.

The Committee on Membership reported that it had compiled a list of Fellows residing in North America west of the 104th meridian.

An election of officers for the ensuing year was held, resulting in the election of Dr H. W. Fairbanks as Chairman of the Section, A. C. Lawson, Secretary, and W. C. Knight, Councilor.

These three officers are to serve as an Executive Committee for the year.

The Secretary was authorized to send a telegram of greeting to the Society, then in session at Washington, D. C.

The following papers were then read and discussed :

SYNTHESIS OF CHALCOCITE AND ITS GENESIS AT BUTTE, MONTANA

BY HORACE V. WINCHELL

The paper is printed in this volume, pages 269–276.

GEOLOGICAL RECONNAISSANCE OF THE REGION OF THE UPPER MAIN WALKER RIVER, NEVADA

BY D. T. SMITH *

An abstract of the paper is printed in the Journal of Geology, volume xi, page 94.

The Section adjourned to meet at South Hall, Berkeley, at 2 o'clock p m.

At 2 o'clock the Section was called to order, the Chairman, H. W. Fairbanks, in the chair.

* Presented by Andrew C. Lawson.

The following papers were read and discussed:

CORRELATION OF THE JOHN DAY AND THE MASCALL

BY JOHN C. MERRIAM AND W. J. SINCLAIR

An abstract of the paper is printed in the Journal of Geology, volume xi, pages 95–96.

VALLEYS OF SOUTHERN CALIFORNIA

BY E. W. HILGARD

A short abstract is printed in the Journal of Geology, volume xi, page 96.

POTTER CREEK QUATERNARY BONE CAVE

BY WILLIAM J. SINCLAIR*

The paper is published in Science, volume 17, May, 1903, pages 708–712.

The Section then adjourned.

SESSION OF THE CORDILLERAN SECTION, WEDNESDAY, DECEMBER 31

The Section met at 9.30 o'clock a m in South Hall, Berkeley, Dr H. W. Fairbanks in the chair. The following papers were read and discussed:

PHYSIOGRAPHY OF SOUTHERN ARIZONA AND NEW MEXICO

BY H. W. FAIRBANKS

An abstract is printed in the Journal of Geology, volume xi, pages 97–99.

SOME GYPSUM DEPOSITS OF NORTHWESTERN NEVADA

BY GEORGE D. LOUDERBACK

An abstract of the paper is printed in the Journal of Geology, volume xi, page 99.

PHYSIOGRAPHY AND GEOLOGY OF THE SISKIYOU RANGE

BY F. M. ANDERSON

An abstract of the paper is printed in the Journal of Geology, volume xi, page 100.

The Section then adjourned till 2 o'clock p m.

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*Presented by J. C. Merriam.

At 2 o'clock the Section reconvened, Dr H. W. Fairbanks in the chair, and the following papers were read and discussed :

GENESIS OF ORE DEPOSITS IN BOULDER COUNTY, COLORADO

BY RUFUS M. BAGG, JR.

[*Abstract*]

The geology of Boulder county was outlined, and the formation of veins was considered. A description was given of the occurrence of fissure veins along irregular fracture zones which, after faulting, have been secondarily filled with solutions and sublimation products, chiefly the tellurides of gold, mercury, and the sulphide of iron, marcasite. The genesis of these rich ore pockets was discussed. A description of some of the principal mines and a summary of field observations when examining mines in the district were given.

LEUCITE HILLS OF WYOMING

BY J. F. KEMP AND W. C. KNIGHT

Mr Knight presented this paper before the Cordilleran Section at the same time Professor Kemp read it at the Washington meeting. It is printed as pages 305–336 of this volume.

*MECHANICS OF IGNEOUS INTRUSION**

BY R. A. DALY

This paper is published in the American Journal of Science, volume xv, April, 1903, page 269 *et sequitur*.

The following papers were read by title:

PROBABLE CAUSE OF WATER FLOW IN THE MINES OF CRIPPLE CREEK, COLORADO

BY RUFUS M. BAGG, JR.

PADDLES OF SHASTASAURUS

BY JOHN C. MERRIAM

QUATERNARY OF THE MIDDLE COAST RANGES OF CALIFORNIA

BY ANDREW C. LAWSON

STRUCTURAL SECTION OF A BASIN RANGE

BY GEORGE D. LOUDERBACK

An abstract of the paper is printed in the Journal of Geology, volume xi, pages 102–103.

The Section then adjourned.

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* Presented by Andrew C. Lawson.

Register of the San Francisco Meeting of the Cordilleran Section, 1902

The following Fellows were in attendance at the meeting:

A. S. Eakle.
W. C. Knight.
G. D. Louderback.
F. M. Anderson.
E. W. Hilgard.
H. W. Fairbanks.
A. C. Lawson.

The following visitors were present:

J. W. Sinclair.
D. T. Smith.
G. J. Young.
V. C. Osmont.
A. Knopf.
W. E. Cahill.
E. L. Furlong.

Andrew C. Lawson,
Secretary.

ACCESSIONS TO LIBRARY FROM JUNE, 1902, TO JUNE, 1903

By H. P. Cushing, *Librarian*

Contents

(*A*) From Societies and Institutions receiving the Bulletin as Donation ("Exchanges")

(*a*) *AMERICA*

NEW YORK STATE MUSEUM, ALBANY

2309. Annual Report no. 54, part 1.
Bulletins nos. 49–54.

BOSTON SOCIETY OF NATURAL HISTORY, BOSTON

2133. Proceedings, vol. 30, nos. 4–7, 1901–'02.
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MUSEO NACIONAL DE BUENOS AIRES, BUENOS AIRES

1539. Comunicaciones, tomo 1, núm. 10.
2279. Anales, tomo vii (new series iv).
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CHICAGO ACADEMY OF SCIENCES, CHICAGO

1694. Bulletin of the Natural History Survey, no. 3, part 2, 1902.
2257. " " " " " " no. 5, 1902.
2258. Special Publications, no. 1, 1902.

FIELD COLUMBIAN MUSEUM, CHICAGO

1000. Publication 64, Geological Series, vol. i, no. 11, 1902.
1916. " 65, Zoological Series, vol. iii, nos. 6–9, 1902.
2181. " 67, Report Series, vol. ii, no. 2, 1902.

CINCINNATI SOCIETY OF NATURAL HISTORY, CINCINNATI

2149. Journal, vol. xx, no. 3.

COLORADO SCIENTIFIC SOCIETY, DENVER

2283. Proceedings, vol. vi, 1897–'00.
2390. Four separate papers.

NOVA SCOTIAN INSTITUTE OF SCIENCE, HALIFAX

1771. Proceedings and Transactions, vol. x, parts 3 and 4.

MUSEO DE LA PLATA, LA PLATA

2280. Revista, tomo x, 1902.
2281. Anales, Seccion Geologica y Mineralogica, III.

INSTITUTO GEOLOGICO DE MEXICO, MEXICO

2327. Boletin, numero 16, 1902.

NATURAL HISTORY SOCIETY OF MONTREAL, MONTREAL

1946. Canadian Record of Science, vol. viii, no. 8.

AMERICAN GEOGRAPHICAL SOCIETY, NEW YORK

2172. Bulletin, vol. xxxiv, nos. 3–5, 1902.
2326. " vol. xxxv, no. 1, 1903.

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1693. Annual Report of the President, etcetera, 1901–1902.
2150. Bulletin, vol. xvii, part 2, 1902.
2266. " vol. xviii, part i, 1902.

NEW YORK ACADEMY OF SCIENCES, NEW YORK

GEOLOGICAL SURVEY OF CANADA, OTTAWA

2282. Geological Map of Canada, western sheet, 1902.
2352. Geographic Map of Manitoba.

ROYAL SOCIETY OF CANADA, OTTAWA

ACADEMY OF NATURAL SCIENCES, PHILADELPHIA

2231. Proceedings, vol. liv, parts 1–3, 1902.

AMERICAN PHILOSOPHICAL SOCIETY, PHILADELPHIA

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2163. Transactions, vol. xii, nos. 5–10, 1902.

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2136. National Geographic Magazine, vol. xiii, nos. 5–12, 1902.
2292. " " " " xiv, nos. 1–6, 1903.

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2289. Annual Report for 1901.

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2250–2252. Twenty-first Annual Report, part 5, with atlas, and part 7.
2320–2323. Twenty-second Annual Report, parts 1–4.
2159. Bulletin 179.
2268–2271. Bulletins 180–194.
2305–2306. Bulletins 195–204.
2307–2308. Mineral Resources, 1900–1901.
2267. Monograph xli.
2253. Geology and Mineral Resources of the Copper River District, Alaska.
2254. Reconnaissance in the Cape Nome Region, Alaska.

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(*b*) *EUROPE*

DEUTSCHE GEOLOGISCHE GESELLSCHAFT, BERLIN

2244. Zeitschrift, band liv, heft 1–2, 1902.

KÖNIGLICH PREUSSISCHEN GEOLOGISCHEN LANDESANSTALT UND BERGAKADEMIE, BERLIN

2246. Jahrbuch, band xxii, 1900.

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SCHWEIZ GEOLOGISCHEN GESELLSCHAFT, BERNE

2332. Lieferung XIII, neue folge.
2333. Maps, Environs de Moutier et Bellelay, et Lagern, with text.

R. ACCADEMIA DELLE SCIENZE DELL' INSTITUTO DI BOLOGNA, BOLOGNA

2301. Rendiconto, nuova serie, vol. iv, fasc. 1–4.
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NATURHIST. VEREINS DES PREUSSISCHEN RHEINLANDE, WESTFALENS, UND DES REG.-BEZIRKS OSNABRÜCK, BONN

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2240. Bulletin de la Classe des Sciences, 1901.
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2348. " 1903.

SOCIÉTÉ BELGE DE GÉOLOGIE, DE PALÉONTOLOGIE, ET D'HYDROLOGIE, BRUSSELS

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2349. Nouveaux Memoires, serie in 4°, fasc. 1.

BIUROULI GEOLOGICA, BUCHAREST

MAGYARHONI FÖLDTANI TARSULAT, BUDAPEST

2060. Földtani közlöny, xxxi kötet, 10–12 fuset, 1901.
2238. " " xxxii kötet, 1–9 fuset, 1902.

NORGES GEOLOGISKA UNDERSOGELSE, CHRISTIANA

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2302. Raekke I, nr. 9.
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DET KONGELIGE DANSKE VIDENSKABERNES SELSKAB, COPENHAGEN

2237. Oversigt i Aaret, Förhandlingar, 1902, nr. 4–6.
2236. Memoires, 6me serie, tome xi, no 4.
2351. Oversigt i Aaret, Förhandlingar, 1903, nr. 1.

NATURWISSENSCHAFTLICHEN GESELLSCHAFT ISIS, DRESDEN

2286. Sitzungsberichte und Abhandlungen, Jahrgang 1902.

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NATURFORSCHENDEN GESELLSCHAFT, FREIBURG, I. B.

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GEOLOGICAL SOCIETY OF GLASGOW, GLASGOW

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GEOLOGISKA UNDERSOKNING, HELSINGFORS

2248. Meddelanden från industristyrelsen, häftet 32–33.
2249. Geologisk Öfversiktskarta öfver Finland, 1902.
2260. Bulletins, nos. 9, 12–13.

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1710. Sammlungen, band vi, heft 5, 1902.
2331. " band vii, heft 1–2, 1902.
2047. Beiträge zur Geologie von Niederländisch West-Indien, Band ii, heft 2.

K. SACHSISCHE GESELLSCHAFT DER WISSENSCHAFTEN, LEIPSIG

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2189. Abhandlungen der math. phys. classe, band xxvii, nos. 4–9.

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2350. "Southern Cross" Collections.

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1679. Geological Literature, 8.
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2288. Geological Survey of Scotland, Memoirs, Geology of Eastern Fife.
2290. Summary of Progress, 1901.
2291. Memoirs, Berkshire Water Supply.
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2312. Summary of Progress for 1899–1900.
2330. Geological Survey of Ireland, Memoirs, Geology of the Country around Dublin.

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2353. " vol. xviii, part 1.

COMISION DEL MAPA GEOLOGICA DE ESPAÑA, MADRID

2226. Memorias, tomo iv, Explication del Mapa Geologica de España.
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SOCIETA ITALIANA DI SCIENZE NATURALI, MILAN

2198. Atti, vol. xli, fasc. 2–4, 1902.

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2173. Bulletin, Année, 1901, nos. 3–4.
2225. " " 1902, nos. 1–2.

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2294. " " " " 1902, heft 1–2.

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2046. Catalogue of books added during 1901.

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2265. " " " tome ii, livr. 7–12 de 1902.
2345. " " " tome iii, livr. 1–2 de 1903.

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2194. " " " tome ii, nos. 2–4, 1902.
2352. " " " tome iii, no. 1, 1903.

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2232. Bolletino, vol. xxxiii, N. 1–3, 1902.

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COMITÈ GÉOLOGIQUE DE LA RUSSIE, ST PETERSBURG

Explorations géologiques dans les régions aurifères de la Sibérie.
2262. Region aurifère de l'Amour, livr. 1–2.
2263. " " d'Iénissei, livr. 1–2.
2264. " " de Lena, livr. 1.
1173. Memoirs, vol. xv, no. 4.
2341. " vol. xvii, nos. 1–2.
2176. " vol. xviii, no. 3.
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2343. " vol. xx, no. 2.
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2175. Verhandlungen, zweite serie, band xxxix, lief. 2.

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2273. Sveriges Geologiska Undersökning, Ser. Ba, no. 6, with maps.
2274. " " " Ser. C, nos. 183–192.
2275. Geologisk Karta öfver Blekinge Lån, 2 sheets.
2276. Sveriges Geologiska Undersökning, series Ca, nos. 1–2.
2277. " " " " Ac, nos. 1–4 and 6.
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2285. " " " " Bf, no. 9.
1470. " " " " C, nos. 172 and 180.

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2161. Förhandlingar, band xxiv, häfte 3–7, 1902.
2313. " band xxv, häfte 1–4, 1903.

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2335. " 1903, nos. 1–4.
2165. Neues Jahrbuch, 1902, band i, heft 3.
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(c) *ASIA*

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2186. " vol. xxxiv, part 2.
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2325. General Report for 1901–1902.

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2256. Geological and Topographical Maps of the Oil Fields of Japan; section I, Higashiyama Oil Field.
2318. Geological Map of Japan, scale 1–1000000, with text.
2319. Geological Map of Japan, Kōchi, Uwajima, and Wakayama sheets, with text.

(d) *AUSTRALASIA*

GEOLOGICAL DEPARTMENT OF SOUTH AUSTRALIA, ADELAIDE

1515. Record of the Mines, Tarcoola and the Northwestern District.
2297. Northern District, White Range Gold Mines.
2299. Contributions to the Paleontology of S. A., nos. 12–13.

GEOLOGICAL SURVEY OF QUEENSLAND, BRISBANE

2169. Annual Progress Report, 1901.
2284. Two Separate Reports on Coal Beds.
2314. Separate Reports, nos. 167–169, 172–173, and 176, 4to.
2315. Reports nos. 177, 179–180, 8vo.
2316. Index no. 2, Index to Reports, 136–177.

CANTERBURY MUSEUM, CHRISTCHURCH

DEPARTMENT OF MINES OF VICTORIA, MELBOURNE

2227. Report on the Pitfield Plains Gold Field.
2317. Annual Report of the Secretary of Mines for 1901.
2344. Records of the Geological Survey, vol. i, part 1.

GEOLOGICAL DEPARTMENT OF WESTERN AUSTRALIA, PERTH

1499. Bulletin no. 6, 1902.
2296. Kalgoorlie and Lennonville Map Sheets.

GEOLOGICAL SURVEY OF NEW SOUTH WALES, SYDNEY

2247. Handbook to the Mining and Geological Museum, Sydney, 1902.
2044. Records of the Geological Survey, vol. vii, part 2, 1902.
2287. Annual Report of the Department of Mines for 1901.

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(*e*) *AFRICA*

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2272. Annual Report for 1900.

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2180. First Report of the Geological Survey, 1901.

(*f*) *HAWAIIAN ISLANDS*

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(*B*) FROM STATE GEOLOGICAL SURVEYS AND MINING BUREAUS

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2360. Bulletins nos. 2–5, 1902.

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2339. Report, vol. vii, Mineral Waters.
2361. Mineral Resources of Kansas, 1900–'01.

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2362. Annual Report for 1901.
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2325. Final Report, vol. v, Glacial Geology.
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(*a*) *AMERICA*

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2364. Boletin, tomo iv, num. 1.

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2366. Bulletin, vol. iii, nos. 3–4, 1901.

(*b*) *EUROPE*

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2367. Sitzungsberichte und Abhandlungen, 1898–1901.

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2245. Seventy-ninth Jahresbericht, 1901.

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2368. Rapport sur les Variations des Glaciers Française de 1900 à 1901. Revue de Glaciologie.

NATURFORSCHER-VEREINS ZU RIGA, RIGA

2369. Korrespondenzblatt, xlv, 1902.

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2370. Travaux, vol. v, 1902.

(*c*) *ASIA*

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2372. Journal of Geography, vol. xiv, 1902.

(*D*) FROM FELLOWS OF THE GEOLOGICAL SOCIETY OF AMERICA (PERSONAL PUBLICATIONS)

WHITMAN CROSS

2373. Geologic Formations *versus* Lithologic Individuals.

CROSS, IDDINGS, PIRSSON, AND WASHINGTON

2295. Quantitative Cassification of Igneous Rocks.

ANGELO HEILPRIN

2374. A Defense of the Panama Route.

C. F. MARBUT

2375. The Evolution of the Northern Part of the Lowlands of Southeastern Missouri.

GEORGE P. MERRILL

2376. A newly found Meteorite from Admire, Lyon county, Kansas.

CHARLES SCHUCHERT

2377. On the lower Devonic and Ontaric Formations of Maryland.

CHARLES D. WALCOTT

2378. Cambrian Brachiopoda; Obolella, etcetera, with descriptions of new species.

2379. Cambrian Brachiopoda; Acrotreta, etcetera, with descriptions of new species.

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DR AUGUST BÖHM EDLEN VON BÖHMERSHEIM

2381. Geschichte der Moränenkunde.

STANISLAUS MEUNIER

2382. Études Géologiques sur le Terrain Quarternaire du Canton de Vaud.
2383. Sur l'Origine et le Mode de Formation du Mineral de Fer oolithique de Lorraine.

WILLIAM BRADFORD, BALLARAT

2384. The Creswick Field and its Mining.

W. PRINZ, BRUSSELS

2385. L'Hypothèse de la Déformation Tétraédrique de la Terre.

ALEXANDER v. KALECSINSKY

2386. Über die Ungarischen Warned und Heissen Kochsalzseen, etcetera.

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2387. Excursión á la Sierra de la Ventana, Apuntes geológicos de las Sierras de Olavarria.

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2388. The Casas Grandes Meteorite.
2389. Descriptive Catalogue of the Meteorite Collection in the U. S. National Museum to January 1, 1902.

OFFICERS AND FELLOWS OF THE GEOLOGICAL SOCIETY OF AMERICA

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I. C. White, Morgantown, W. Va.

Editor

J. Stanley-Brown, Washington, D. C.

Librarian

H. P. Cushing, Cleveland, Ohio.

Councillors

(Term expires 1903)

Samuel Calvin, Iowa City, Iowa
A. P. Coleman, Toronto, Canada

(Term expires 1904)

C. W. Hayes, Washington, D. C.
J. P. Iddings, Chicago, Ill.

(Term expires 1905)

R. D. Salisbury, Chicago, Ill.
J. E. Wolff, Cambridge, Mass.

FELLOWS IN JANUARY, 1904

* Indicates Original Fellow (see article III of Constitution)

Cleveland Abbe, Jr., Ph. D., 2017 I St. N. W., Washington, D. C. August, 1899.

Frank Dawson Adams, Ph. D., Montreal, Canada; Professor of Geology in McGill University. December, 1889.

George I. Adams, Sc. D., U. S. Geological Survey, Washington, D. C. December, 1902.

José Guadalupe Aguilera, Esquela N. de Ingeneiros, City of Mexico, Mexico; Director del Instituto Geologico de Mexico. August, 1896.

Truman H. Aldrich, M. E., Birmingham, Ala. May, 1889.

Henry M. Ami, A. M., Geological Survey Office, Ottawa, Canada; Assistant Paleontologist on Geological and Natural History Survey of Canada. December, 1889.

Frank M. Anderson, B. A., M. S., 2604 Ætna Street, Berkeley, Cal. In California State Mining Bureau. June, 1902.

Philip Argall, 821 Equitable Building, Denver, Colo.; Mining Engineer. August, 1896.

George Hall Ashley, M. E., Ph. D., Washington, D. C., U. S. Geological Survey. August, 1895.

Harry Foster Bain, M. S., U. S. Geological Survey, Washington, D. C. December, 1895.

Rufus Mather Bagg, Ph. D., Socorro, N. Mex.; Professor of Mineralogy and Petrography, State School of Mines. December, 1896.

S. Prentiss Baldwin, 736 Prospect St., Cleveland, Ohio. August, 1895.

Erwin Hinckley Barbour, Ph. D., Lincoln, Neb.; Professor of Geology, University of Nebraska, and Acting State Geologist. December, 1896.

Joseph Barrell, Ph. D., New Haven, Conn.; Yale University Museum. December, 1902.

George H. Barton, B. S., Boston, Mass.; Instructor in Geology in Massachusetts Institute of Technology. August, 1890.

Florence Bascom, Ph. D., Bryn Mawr, Pa.; Instructor in Geology, Petrography, and Mineralogy in Bryn Mawr College. August, 1894.

William S. Bayley, Ph. D., Waterville, Me.; Professor of Geology in Colby University. December, 1888.

*George F. Becker, Ph. D., Washington, D. C.; U. S. Geological Survey.

Charles E. Beecher, Ph. D., Yale University, New Haven, Conn. May, 1889.

Joshua W. Beede, Ph. D., Bloomington, Ind.; Instructor in Geology, Indiana University. December, 1902.

Robert Bell, C. E., M. D., LL. D., Ottawa, Canada; Acting Director of the Geological and Natural History Survey of Canada. May, 1889.

Charles P. Berkey, Ph. D., New York city; Columbia University. August, 1901.

Samuel Walker Beyer, Ph. D., Ames, Iowa; Assistant Professor in Geology, Iowa Agricultural College. December, 1896.

Albert S. Bickmore, Ph. D., American Museum of Natural History, New York; Professor in charge of Department of Public Instruction. December, 1889.

Irving P. Bishop, 109 Norwood Ave., Buffalo, N. Y.; Professor of Natural Science, State Normal and Training School. December, 1899.

*John C. Branner, Ph. D., Stanford University, Cal.; Professor of Geology in Leland Stanford, Jr., University.

Albert Perry Brigham, A. B., A. M., Hamilton, N. Y.; Professor of Geology and Natural History, Colgate University. December, 1893.

Alfred Hulse Brooks, B. S., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1899.

Ernest Robertson Buckley, Ph. D., Rolla, Mo.; State Geologist and Director of Bureau of Geology and Mines. June, 1902.

*Samuel Calvin, Iowa City, Iowa; Professor of Geology and Zoology in the State University of Iowa; State Geologist.

Henry Donald Campbell, Ph. D., Lexington, Va.; Professor of Geology and Biology in Washington and Lee University. May, 1889.

Marius R. Campbell, U. S. Geological Survey, Washington, D. C. August, 1892.

Franklin R. Carpenter, Ph. D., 1420 Josephine St., Denver, Colo.; Mining Engineer. May, 1889.

Ermine C. Case, Ph. D., Milwaukee, Wis.; Instructor in State Normal School. December, 1901.

*T. C. Chamberlin, LL. D., Chicago, Ill.; Head Professor of Geology, University of Chicago.

Clarence Raymond Claghorn, B. S., M. E., Wehrum, Indiana county, Pennsylvania. August, 1891.

*William Bullock Clark, Ph. D., Baltimore, Md.; Professor of Geology in Johns Hopkins University; State Geologist.

John Mason Clarke, A. M., Albany, N. Y.; State Paleontologist. December, 1897.

J. Morgan Clements, Ph. D., 11 William St., New York City. December, 1894.

Collier Cobb, A. B., A. M., Chapel Hill, N. C.; Professor of Geology in University of North Carolina. December, 1894.

Arthur P. Coleman, Ph. D., Toronto, Canada; Professor of Geology, Toronto University, and Geologist of Bureau of Mines of Ontario. December, 1896.

George L. Collie, Ph. D., Beloit, Wis.; Professor of Geology in Beloit College. December, 1897.

Arthur J. Collier, A. M., S. B., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. June, 1902.

*Theodore B. Comstock, Sc. D., Los Angeles, Cal.; Mining Engineer.

*Francis W. Cragin, Ph. D., Colorado Springs, Colo.; Professor of Geology in Colorado College.

Alja Robinson Crook, Ph. D., Evanston, Ill.; Professor of Mineralogy and Economic Geology in Northwestern University. December, 1898.

*William O. Crosby, B. S., Boston Society of Natural History, Boston, Mass.; Assistant Professor of Mineralogy and Lithology in Massachusetts Institute of Technology.

Whitman Cross, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

Garry E. Culver, A. M., 1104 Wisconsin St., Stevens Point, Wis. December, 1891.

Edgar R. Cumings, Ph. D., Bloomington, Ind.; Assistant Professor of Geology, Indiana University. August, 1901.

*Henry P. Cushing, M. S., Adelbert College, Cleveland, Ohio; Professor of Geology, Western Reserve University.

*Nelson H. Darton, United States Geological Survey, Washington, D. C.

*William M. Davis, S. B., M. E., Cambridge, Mass.; Sturgis-Hooper Professor of Geology in Harvard University.

David T. Day, Ph. D., U. S. Geol. Survey, Washington, D. C. August, 1891.

Orville A. Derby, M. S., Sao Paulo, Brazil; Director of the Geographical and Geological Survey of the Province of Sao Paulo, Brazil. December, 1890.

*Joseph S. Diller, B. S., United States Geological Survey, Washington, D. C.

Edward V. d'Invilliers, E. M., 506 Walnut St., Philadelphia, Pa. Dec., 1888.

Richard E. Dodge, A. M., Teachers' College, West 120th St., New York city; Professor of Geography in the Teachers' College. August, 1897.

Noah Fields Drake, Ph. D., Tientsin, China; Professor of Geology in Imperial Tientsin University. December, 1898.

Charles R. Dryer, M. A., M. D., Terre Haute, Ind.; Professor of Geography, Indiana State Normal School. August, 1897.

*Edwin T. Dumble, Austin, Texas; State Geologist.

*William B. Dwight, Ph. B., Poughkeepsie, N. Y.; Professor of Natural History in Vassar College.

Arthur S. Eakle, Ph. D., Berkeley, Cal.; Instructor in Mineralogy, University of California. December, 1899.

Charles R. Eastman, A. M., Ph. D., Cambridge, Mass.; In charge of Vertebrate Paleontology, Museum of Comparative Zoology, Harvard University. December, 1895.

*George H. Eldridge, A. B., United States Geological Survey, Washington, D. C.

Arthur H. Elftman, Ph. D., 706 Globe Building, Minneapolis, Minn. December, 1898.

*Benjamin K. Emerson, Ph. D., Amherst, Mass.; Professor in Amherst College.

*Samuel F. Emmons, A. M., E. M., United States Geological Survey, Washington, D. C.

John Eyerman, F. Z. S., Oakhurst, Easton, Pa. August, 1891.

Harold W. Fairbanks, B. S., Berkeley, Cal.; Geologist State Mining Bureau. August, 1892.

*Herman L. Fairchild, B. S., Rochester, N. Y.; Professor of Geology in University of Rochester.

J. C. Fales, Danville, Kentucky; Professor in Centre College. December, 1888.

Oliver C. Farrington, Ph. D., Chicago, Ill.; In charge of Department of Geology, Field Columbian Museum. December, 1895.

August F. Foerste, Ph. D., 417 Grand Ave., Dayton, Ohio; Teacher of Sciences. December, 1899.

William M. Fontaine, A. M., University of Virginia, Va.; Professor of Natural History and Geology in University of Virginia. December, 1888.

*Persifor Frazer, D. Sc., 1042 Drexel Building, Philadelphia, Pa.; Professor of Chemistry in Horticultural Society of Pennsylvania.

*Homer T. Fuller, Ph. D., Springfield, Mo.; President of Drury College.

Myron Leslie Fuller, S. B., U. S. Geological Survey, Washington, D. C. December, 1898.

Henry Stewart Gane, Ph. D., Santa Barbara, Cal.; December, 1896.

Henry Gannett, S. B., A. Met. B., U. S. Geological Survey, Washington, D. C. December, 1891.

*Grove K. Gilbert, A. M., LL. D., United States Geological Survey, Washington, D. C.

ADAM CAPEN GILL, Ph. D., Ithaca, N. Y.; Assistant Professor of Mineralogy and Petrography in Cornell University. December, 1888.

L. C. GLENN, Ph. D., Nashville, Tenn.; Professor of Geology in Vanderbilt University. June, 1900.

CHARLES H. GORDON, Ph. D., University Sta., Seattle, Wash.; Acting Professor of Geology, University of Washington. August, 1893.

AMADEUS W. GRABAU, S. B., Columbia University, New York city; Lecturer on Paleontology. December, 1898.

ULYSSES SHERMAN GRANT, Ph. D., Evanston, Ill.; Professor of Geology, Northwestern University. December, 1890.

HERBERT E. GREGORY, Ph. D., New Haven, Conn.; Assistant Professor of Physiography, Yale University. August, 1901.

WILLIAM S. GRESLEY, 115 Radbourne St., Derby, England. Mining Engineer. December, 1893.

GEORGE P. GRIMSLEY, Ph. D., Topeka, Kans.; Professor of Geology in Washburn College. August, 1895.

LEON S. GRISWOLD, A. B., 238 Boston St., Dorchester, Mass. August, 1902.

FREDERIC P. GULLIVER, Ph. D., St. Mark's School, Southboro, Mass. August, 1895.

ARNOLD HAGUE, Ph. B., United States Geological Survey, Washington, D. C. May, 1889.

*CHRISTOPHER W. HALL, A. M., 803 University Ave., Minneapolis, Minn.; Professor of Geology and Mineralogy in University of Minnesota.

JOHN BURCHMORE HARRISON, M. A., F. I. C., F. G. S., Georgetown, British Guiana; Government Geologist. June, 1902.

JOHN B. HASTINGS, M. E., Stanley, Custer Co., Idaho. May, 1889.

JOHN B. HATCHER, Ph. B., Carnegie Museum, Pittsburg, Pa. August, 1895.

*ERASMUS HAWORTH, Ph. D., Lawrence, Kans.; Professor of Geology, University of Kansas.

C. WILLARD HAYES, Ph. D., United States Geological Survey, Washington, D. C. May, 1889.

*ANGELO HEILPRIN, Academy of Natural Sciences, Philadelphia, Pa.; Professor of Paleontology in the Academy of Natural Sciences.

*EUGENE W. HILGARD, Ph. D., LL. D., Berkeley, Cal.; Professor of Agriculture in University of California.

FRANK A. HILL, Roanoke, Va. May, 1889.

*ROBERT T. HILL, B. S., U. S. Geological Survey, Washington, D. C.

RICHARD C. HILLS, Mining Engineer, Denver, Colo. August, 1894.

*CHARLES H. HITCHCOCK, Ph. D., LL. D., Hanover, N. H.; Professor of Geology in Dartmouth College.

WILLIAM HERBERT HOBBS, Ph. D., Madison, Wis.; Professor of Mineralogy and Petrology, University of Wisconsin; Assistant Geologist, U. S. Geological Survey. August, 1891.

*LEVI HOLBROOK, A. M., P. O. Box 536, New York city.

ARTHUR HOLLICK, Ph. B., N. Y. Botanical Garden, Bronx Park, New York; Instructor in Geology, Columbia University. August, 1893.

*JOSEPH A. HOLMES, St. Louis, Mo.; Chief of Department of Mines and Metallurgy, Universal Exposition; State Geologist and Professor of Geology, University of North Carolina.

Thomas C. Hopkins, Ph. D., Syracuse, N. Y.; Professor of Geology, Syracuse University. December, 1894.

*Edmund Otis Hovey, Ph. D., American Museum of Natural History, New York city; Assistant Curator of Geology.

*Horace C. Hovey, D. D., Newburyport, Mass.

*Edwin E. Howell, A. M., 612 Seventeenth St. N. W., Washington, D. C.

Lucius L. Hubbard, Ph. D., LL. D., Houghton, Mich. December, 1894.

Joseph P. Iddings, Ph. B., Professor of Petrographic Geology, University of Chicago, Chicago, Ill. May, 1889.

A. Wendell Jackson, Ph. B., 432 St. Nicholas Ave., New York city. December, 1888.

Robert T. Jackson, S. D., 9 Fayerweather St., Cambridge, Mass.; Instructor in Paleontology in Harvard University. August, 1894.

Thomas M. Jackson, C. E., S. D., Clarksburg, W. Va. May, 1889.

Alexis A. Julien, Ph. D., Columbia College, New York city; Instructor in Columbia College. May, 1889.

Arthur Keith, A. M., United States Geological Survey, Washington, D. C. May, 1889.

*James F. Kemp, A. B., E. M., Columbia University, New York city; Professor of Geology.

Charles Rollin Keyes, Ph. D., Socorro, N. Mex.; President, State School of Mines. August, 1890.

Frank H. Knowlton, M. S., Washington, D. C.; Assistant, Paleontologist, U. S. Geological Survey. May, 1889.

Edward Henry Kraus, Ph. D., Syracuse, N. Y.; Head of Department of Science, Syracuse High School. June, 1902.

Henry B. Kümmel, Ph. D., Trenton, N. J.; State Geologist. December, 1895.

*George F. Kunz, care Tiffany & Co., 15 Union Square, New York city.

George Edgar Ladd, Ph. D., Rolla, Mo.; Director School of Mines. August, 1891.

J. C. K. Laflamme, M. A., D. D., Quebec, Canada; Professor of Mineralogy and Geology in University Laval, Quebec. August, 1890.

Alfred C. Lane, Ph. D., Lansing, Mich.; State Geologist of Michigan. December, 1889.

Daniel W. Langton, Ph. D., Fuller Building, New York city; Mining Engineer. December, 1889.

Andrew C. Lawson, Ph. D., Berkeley, Cal.; Professor of Geology and Mineralogy in the University of California. May, 1889.

Charles K. Leith, Ph. D., Madison, Wis.; Assistant Professor of Geology, University of Wisconsin. December, 1902.

Arthur G. Leonard, Ph. D., Grand Forks, N. Dak.; Professor of Geology and State Geologist, State University of North Dakota. December, 1901.

Frank Leverett, B. S., Ann Arbor, Mich.; Geologist, U. S. Geological Survey. August, 1890.

William Libbey, Sc. D., Princeton, N. J., Professor of Physical Geography in Princeton University. August, 1899.

Waldemar Lindgren, M. E., U. S. Geological Survey, Washington, D. C. August, 1890.

George Davis Louderback, Ph. D., Reno, Nev.; Professor of Geology, University of Nevada. June, 1902.

Robert H. Loughridge, Ph. D., Berkeley, Cal.; Assistant Professor of Agricultural Chemistry in University of California. May, 1889.

Thomas H. Macbride, A. M., Iowa City, Iowa: Professor of Botany in the State University of Iowa. May, 1889.

Henry McCalley, A. M., C. E., University, Tuscaloosa county, Ala.; Assistant on Geological Survey of Alabama. May, 1889.

Richard G. McConnell, A. B., Geological Survey Office, Ottawa, Canada; Geologist on Geological and Natural History Survey of Canada. May, 1889.

James Rieman Macfarlane, A. B., 100 Diamond St., Pittsburg, Pa. August, 1891.

* W J McGee, Washington, D. C.; Chief of Department of Anthropology, Universal Exposition, St. Louis.

William McInnes, A. B., Geological Survey Office, Ottawa, Canada; Geologist, Geological and Natural History Survey of Canada. May, 1889.

Peter McKellar, Fort William, Ontario, Canada. August, 1890.

Curtis F. Marbut, A. M., State University, Columbia, Mo.; Instructor in Geology and Assistant on Missouri Geological Survey. August, 1897.

Vernon F. Marsters, A. M., Bloomington, Ind.; Professor of Geology in Indiana State University. August, 1892.

George Curtis Martin, Ph. D., Baltimore, Md.; Assistant in Paleontology, Johns Hopkins University. June, 1902.

Edward B. Mathews, Ph. D., Baltimore, Md.; Instructor in Petrography in Johns Hopkins University. August, 1895.

P. H. Mell, M. E., Ph. D., Clemson College, S. C.; President of Clemson College. December, 1888.

Warren C. Mendenhall, B. S., Washington, D. C.; Geologist, U. S. Geological Survey. June, 1902.

John C. Merriam, Ph. D., Berkeley, Cal.; Instructor in Paleontology in University of California. August, 1895.

* Frederick J. H. Merrill, Ph. D., State Museum, Albany, N. Y.; Director of State Museum and State Geologist.

George P. Merrill, M. S., U. S. National Museum, Washington, D. C.; Curator of Department of Lithology and Physical Geology. December, 1888.

Arthur M. Miller, A. M., Lexington, Ky.; Professor of Geology, State University of Kentucky. December, 1897.

Willet G. Miller, M. A., Toronto, Canada; Provincial Geologist of Ontario. December, 1902.

* Frank L. Nason, A. B., West Haven, Conn.

Frederick H. Newell, B. S., U. S. Geol. Survey, Washington, D. C. May, 1889.

John F. Newsom, A. M., Stanford University, Cal.; Associate Professor of Metallurgy and Mining. December, 1899.

William H. Niles, Ph. B., M. A., Boston, Mass.; Professor, Emeritus, of Geology, Mass. Inst. of Technology; Professor of Geology, Wellesley College. August, 1891.

William H. Norton, M. A., Mount Vernon, Iowa; Professor of Geology in Cornell College. December, 1895.

Charles J. Norwood, Lexington, Ky.; Professor of Mining, State College of Kentucky. August, 1894.

Ezequiel Ordonez, Esquela N. de Ingeneiros, City of Mexico, Mexico; Geologist del Instituto Geologico de Mexico. August, 1896.

*Amos O. Osborn, Waterville, Oneida county, N. Y.

Henry F. Osborn, Sc. D., Columbia University, New York city; Professor of Zoology, Columbia University. August, 1894.

Charles Palache, B. S., University Museum, Cambridge, Mass.; Instructor in Mineralogy, Harvard University. August, 1897.

*Horace B. Patton, Ph. D., Golden, Colo.; Professor of Geology and Mineralogy in Colorado School of Mines.

Frederick B. Peck, Ph. D., Easton, Pa.; Professor of Geology and Mineralogy, Lafayette College. August, 1901.

Samuel L. Penfield, Ph. B., M. A., New Haven, Conn.; Professor of Mineralogy, Sheffield Scientific School of Yale University. December, 1899.

Richard A. F. Penrose, Jr., Ph. D., 1331 Spruce St., Philadelphia, Pa. May, 1889.

George H. Perkins, Ph. D., Burlington, Vt.; State Geologist. Professor of Geology, University of Vermont. June, 1902.

Joseph H. Perry, 276 Highland St., Worcester, Mass. December, 1888.

*William H. Pettee, A. M., Ann Arbor, Mich.; Professor of Mineralogy, Economical Geology, and Mining Engineering in Michigan University.

Louis V. Pirsson, Ph. D., New Haven, Conn.; Professor of Physical Geology, Sheffield Scientific School of Yale University. August, 1894.

*Julius Pohlman, M. D., University of Buffalo, Buffalo, N. Y.

John Bonsall Porter, E. M., Ph. D., Montreal, Canada; Professor of Mining, McGill University. December, 1896.

Joseph Hyde Pratt, Ph. D., 74 Broadway, New York city. December, 1898.

*Charles S. Prosser, M. S., Columbus, Ohio; Professor of Geology in Ohio State University.

*Raphael Pumpelly, U. S. Geological Survey, Dublin, N. H.

Frederick Leslie Ransome, Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1895.

Harry Fielding Reid, Ph. D., Johns Hopkins Univ., Baltimore, Md. December, 1892.

William North Rice, Ph. D., LL. D., Middletown, Conn.; Professor of Geology in Wesleyan University. August, 1890.

Charles H. Richardson, Ph. D., Hanover, N. H.; Instructor in Chemistry and Mineralogy, Dartmouth College. December, 1899.

Heinrich Ries, Ph. D., Cornell University, Ithaca, N. Y.; Assistant Professor in Economic Geology. December, 1893.

*Israel C. Russell, LL. D., Ann Arbor, Mich.; Professor of Geology in University of Michigan.

*James M. Safford, M. D., LL. D., Dallas, Texas.

Orestes H. St. John, Raton, N. Mex. May, 1889.

*Rollin D. Salisbury, A. M., Chicago, Ill.; Professor of General and Geographic Geology in University of Chicago.

Frederick W. Sardeson, Ph. D., Instructor in Paleontology, University of Minnesota, Minneapolis, Minn. December, 1892.

Frank C. Schrader, M. S., A. M., U. S. Geological Survey, Washington, D. C. August, 1901.

Charles Schuchert, Washington, D. C.; Assistant Curator in Paleontology, U. S. National Museum. August, 1895.

William B. Scott, Ph. D., 56 Bayard Ave., Princeton, N. J.; Blair Professor of Geology in College of New Jersey. August, 1892.

Henry M. Seely, M. D., Middlebury, Vt.; Professor of Geology in Middlebury College. May, 1899.

*Nathaniel S. Shaler, LL. D., Cambridge, Mass.; Professor of Geology in Harvard University.

George Burbank Shattuck, Ph. D., Baltimore, Md.; Associate Professor in Physiographic Geology, Johns Hopkins University. August, 1899.

Edward M. Shepard, A. M., Springfield, Mo.; Professor of Geology, Drury College. August, 1901.

Will H. Sherzer, M. S., Ypsilanti, Mich.; Professor in State Normal School. December, 1890.

*Frederick W. Simonds, Ph. D., Austin, Texas; Professor of Geology in University of Texas.

*Eugene A. Smith, Ph. D., University, Tuscaloosa county, Ala.; State Geologist and Professor of Chemistry and Geology in University of Alabama.

Frank Clemes Smith, B. S., Richland Center, Wis.; Mining Engineer. December, 1898.

George Otis Smith, Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1897.

William S. T. Smith, Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. June, 1902.

*John C. Smock, Ph. D., Trenton, N. J.; State Geologist.

Charles H. Smyth, Jr., Ph. D., Clinton, N. Y.; Professor of Geology in Hamilton College. August, 1892.

Henry L. Smyth, A. B., Cambridge, Mass.; Professor of Mining and Metallurgy in Harvard University. August, 1894.

Arthur Coe Spencer, B. S., Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1896.

*J. W. Spencer, Ph. D., 1733 Q St. N. W., Washington, D. C.

Josiah E. Spurr, A. B., A. M., U. S. Geological Survey, Washington, D. C. December, 1894.

Joseph Stanley-Brown, 128 Broadway, New York. August, 1892.

Timothy William Stanton, B. S., U. S. National Museum, Washington, D. C.; Assistant Paleontologist, U. S. Geological Survey. August, 1891.

*John J. Stevenson, Ph. D., LL. D., New York University; Professor of Geology in the New York University.

William J. Sutton, B. S., E. M., Victoria, B. C.; Geologist to E. and N. Railway Co. August, 1901.

Joseph A. Taff, B. S., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1895.

James E. Talmage, Ph. D., Salt Lake City, Utah. Professor of Geology in University of Utah. December, 1897.

Ralph S. Tarr, Cornell University, Ithaca, N. Y.; Professor of Dynamic Geology and Physical Geography. August, 1890.

Frank B. Taylor, Fort Wayne, Ind. December, 1895.

William G. Tight, M. S., Albuquerque, N. Mex.; President and Professor of Geology, University of New Mexico. August, 1897.

*James E. Todd, A. M., Vermilion, S. Dak.; Assistant Geologist, U. S. Geological Survey.

*Henry W. Turner, B. S., U. S. Geological Survey, San Francisco, Cal.

Joseph B. Tyrrell, M. A., B. Sc., Dawson, Y. T., Canada. May, 1889.

Johan A. Udden, A. M., Rock Island, Ill.; Professor of Geology and Natural History in Augustana College. August, 1897.

*Warren Upham, A. M., Librarian Minnesota Historical Society, St. Paul, Minn.

*Charles R. Van Hise, M. S., Ph. D., Madison, Wis.; President University of Wisconsin; Geologist, U. S. Geological Survey.

Frank Robertson Van Horn, Ph. D., Cleveland, Ohio, Professor of Geology and Mineralogy, Case School of Applied Science. December, 1898.

Thomas Wayland Vaughan, B. S., A. M., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1896.

*Anthony W. Vodges, San Diego, Cal.; Captain Fifth Artillery, U. S. Army.

*Marshman E. Wadsworth, Ph. D., State College, Pa.; Professor of Mining and Geology, Pennsylvania State College.

*Charles D. Walcott, LL. D., Washington, D. C.; Director U. S. Geological Survey.

Charles H. Warren, Ph. D., Boston, Mass.; Instructor in Geology, Massachusetts Institute of Technology. December, 1901.

Henry Stephens Washington, Ph. D., Locust, Monmouth Co., N. J.; August, 1896.

Thomas L. Watson, Ph. D., Granville, Ohio; Professor of Geology, Denison University. June, 1900.

Walter H. Weed, M. E., United States Geological Survey, Washington, D. C. May, 1889.

Stuart Weller, B. S., Chicago, Ill. Instructor in University of Chicago. June, 1900.

Lewis G. Westgate, Ph. D., Delaware, Ohio; Professor of Geology, Ohio Wesleyan University.

Thomas C. Weston, 76 St. Joachim St., Quebec, Canada. August, 1893.

David White, B. S., U. S. National Museum, Washington, D. C.; Assistant Paleontologist, U. S. Geological Survey, Washington, D. C. May, 1889.

*Israel C. White, Ph. D., Morgantown, W. Va.

*Robert P. Whitfield, Ph. D., American Museum of Natural History, 78th St. and Eighth Ave., New York city; Curator of Geology and Paleontology.

*Edward H. Williams, Jr., A. C., E. M., Andover, Mass.

*Henry S. Williams, Ph. D., New Haven, Conn.; Professor of Geology and Paleontology in Yale University.

Bailey Willis, U. S. Geological Survey, Washington, D. C. December, 1889.

Samuel W. Williston, Ph. D., M. D., Chicago, Ill.; Professor of Paleontology, University of Chicago. December, 1898.

Arthur B. Willmott, M. A., Sault Ste. Marie, Ontario, Canada. December, 1899.

Alfred W. G. Wilson, Ph. D., Montreal, Ont., Canada. Demonstrator in Geology, McGill University. June, 1902.

Alexander N. Winchell, Doct. U. Paris, Butte, Mont.; Professor of Geology and Mineralogy, Montana State School of Mines. August, 1901.

*Horace Vaughn Winchell, Butte, Montana; Geologist of the Anaconda Copper Mining Company.

* Newton H. Winchell, A. M., Minneapolis, Minn.; editor *American Geologist.*
* Arthur Winslow, B. S., 84 State St., Boston, Mass.

John E. Wolff, Ph. D., Harvard University, Cambridge, Mass.; Professor of Petrography and Mineralogy in Harvard University and Curator of the Mineralogical Museum. December, 1889.

Robert S. Woodward, C. E., Columbia University, New York city; Professor of Mechanics and Mathematical Physics, Columbia University. May, 1889.

Jay B. Woodworth, B. S., 24 Langdon St., Cambridge, Mass.; Instructor in Harvard University. December, 1895.

Albert A. Wright, Ph. D., Oberlin, Ohio; Professor of Geology in Oberlin College. August, 1893.

*G. Frederick Wright, D. D., Oberlin, Ohio; Professor in Oberlin Theological Seminary.

William S. Yeates, A. B., A. M., Atlanta, Ga.; State Geologist of Georgia. August, 1894.

FELLOWS DECEASED

*Indicates Original Fellow (see article III of Constitution)

*Charles A. Ashburner, M. S., C. E. Died December 24, 1889.
Amos Bowman. Died June 18, 1894.
*J. H. Chapin, Ph. D. Died March 14, 1892.
George H. Cook, Ph. D., LL. D. Died September 22, 1889.
*Edward D. Cope, Ph. D. Died April 12, 1897.
Antonio del Castillo. Died October 28, 1895.
*Edward W. Claypole, D. Sc. Died August 17, 1901.
*James D. Dana, LL. D. Died April 14, 1895.
George M. Dawson, D. Sc. Died March 2, 1901.
Sir J. William Dawson, LL. D. Died November 19, 1899.
*Albert E. Foote. Died October 10, 1895.
N. J. Giroux, C. E. Died November 30, 1890.
*James Hall, LL. D. Died August 7, 1898.
*Robert Hay. Died December 14, 1895.
David Honeyman, D. C. L. Died October 17, 1889.
Thomas Sterry Hunt, D. Sc., LL. D. Died February 12, 1892.
*Alpheus Hyatt, B. S. Died January 15, 1902.
Joseph F. James, M. S. Died March 29, 1897.
Wilbur C. Knight, B. S., A. M. Died July 28, 1903.
Ralph D. Lacoe. Died February 5, 1901.
*Joseph Le Conte, M. D., LL. D. Died July 6, 1901.
*J. Peter Lesley, LL. D. Died June 2, 1903.
Oliver Marcy, LL. D. Died March 19, 1899.
Othniel C. Marsh, Ph. D., LL. D. Died March 18, 1899.
James E. Mills, B. S. Died July 25, 1901.
*Henry B. Nason, M. D., Ph. D., LL. D. Died January 17, 1895.
*Peter Neff, M. A. Died May 11, 1903.
*John S. Newberry, M. D., LL. D. Died December 7, 1892.
*Edward Orton, Ph. D., LL. D. Died October 16, 1899.

* Richard Owen, LL. D. Died March 24, 1890.
* Franklin Platt. Died July 24, 1900.
* John Wesley Powell, LL. D. Died September 23, 1902.
* Charles Schaeffer, M. D. Died November 23, 1903.
Charles Wachsmuth. Died February 7, 1896.
Theodore G. White, Ph. B., A. M. Died July 7, 1901.
* George H. Williams, Ph. D. Died July 12, 1894.
* J. Francis Williams, Ph. D. Died November 9, 1891.
* Alexander Winchell, LL. D. Died February 19, 1891.

Summary

Original Fellows	67
Elected Fellows	186
Membership	253
Deceased Fellows	38

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